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Aerial Application to Southern Pine Seed Orchards

Data Report of the Withlacoochee Trials

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AERIAL APPLICATION TO SOUTHERN PINE SEED ORCHARDS

Data Report of the Withlacoochee Trials

by

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All uses of pesticides must be registered by appropriate state and/or federal agencies before they can be recommended.

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PREFACE

This publication represents a detailed documentation of methods and results of an aerial spray project. The project's purpose was to demonstrate the feasibility of using aircraft to apply pesticides to southern pine seed orchards. This report is somewhat extensive n reporting information and data for reference by those who may pursue related research, technology transfer, or operational activities. With the reporting of all data, the authors hope that testing will not be duplicated because data was not reported. This report should stand as a reference to persons involved in seed orchard pest management. Questions and comments are invited and should be directed to:

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ABSTRACT

The feasibility of using both fixed- and rotary-wing aircraft in the application of pesticides to southern pine seed orchards was evaluated by the USDA Forest Service, Forest Pest Management, in cooperation with the Florida Forest Service. Spray deposit data were collected on spray coverage above the orchard canopy, within the three crowns, and on the orchard floor. Excellent spray coverage was achieved in the tree crowns by both aircraft. A 20-fold increase in application rate was required to achieve spray coverage with ground sprayers. Spray drift was confined within a 133-meter distance downwind from the spray source. Based upon the results of this test, aircraft are recommended as a supplement or substitute to ground sprayers in applying pesticides to southern pine seed orchards.

INTRODUCTION

Protection of pine seed orchards from insect damage is a major concern and responsibility of southern seed orchard managers. There are over 10,000 acres of grafted seed trees in the South, representing substantial investments of dollars and manpower. In 1978, these orchards produced 41 percent of the seed used in southern nurseries. The demand for seed increases yearly, while serious seed losses from insects continues an upward spiral. To illustrate the economic importance of seed and cone insects, losses from a single species can exceed 90 percent in an untreated orchard. Application of chemical pesticides is the only proven method of controlling seed and cone insects in the orchard.

Recent evaluations by USDA Forest Service (FS) entomologists[1] of seed and cone insect damage have shown that there are numerous problems with conventional ground application methods. Hydraulic and mist type sprayers have been used to spray foliage, while specialized seeding equipment may be used to apply systemic materials in granule form. Pesticide application by this equipment has failed as a reliable means to control seed and cone insects. Spraying to "run-off" - a method used with hydraulic sprayers - usually wastes 95 percent of the liquid and often does not wet the plant completely (Metcalf 1958). This is not to suggest that the equipment is faulty in design, but rather this can be attributed to a combination of factors related to ground conditions and access, timing of application, duration of application, physical characteristics of the orchard, tree size and foliage density, spray atomization, physical limitations of equipment, method of using equipment, and operator skill. These factors lead to less than desirable spray coverage on the cones, conelets, and foliage; especially in the upper half of the crown where most of the cones are produced.

Current research in seed orchard management involving pheromone trapping is designed to provide information for critical application timing. Application at peak insect population periods or other defined critical periods often is dependent upon use of aircraft. For this and other reasons, development and implementation of integrated pest management strategies for seed orchards may not be feasible without an aerial application capability.

Past FS work in aerial application has developed an aerial application technology base applicable to southern conifer seed orchards. This technology base provides an opportunity to develop aerial application strategies for seed orchards using spray dispersion, canopy penetration, deposition, and drift models.

State and private seed orchard managers, for the reasons mentioned above, have shown a great deal of interest in aerial application, and a few were experimenting in a "trial and error" fashion with spray aircraft prior to 1981. The FS took the opportunity to provide leadership and direction in developing and recommending aerial application strategies for seed orchards in the South.

PURPOSE

The purpose of this project was to demonstrate the feasibility of applying pesticides to Southern pine seed orchards by aircraft.

Objectives:

1. Compare and evaluate spray deposition on seed orchard pines, resulting from both aerial and ground application.
2. Develop a strategy for aerial application of pesticides to seed orchards which maximizes spray deposition in the target and minimizes spray drift by using the Forest Service, Cramer, Barry. Grim CBG) forest spray model predictions and data obtained from this demonstration.

Demonstrate utility of the FS CBG model in planning, conducting, and evaluating aerial application of pesticides to seed orchards by comparing model predictions to field data.[2]

SCOPE

This cooperative project between the FS and Florida Forest Service was conducted at the Withlacoochee State Seed Orchard, Brooksville, Florida. Aerial release trials began on February 13, 1980, and ended on February 21, 1980. Seven trials involved fixed-wing (Stearman) releases, while five involved helicopter (Hughes 500C) releases (Table 1). In each trial, a tank mix containing water, a salt tracer, and Rhodamine dye was applied at the rate of five gallons per acre. The treatment area consisted of 50 percent Ocala sand pine and 50 percent slash pine. Spray sampling was conducted to determine where the spray was depositing and in what quantity. Concurrently, two ground sprayers were operated and checked to ascertain the quality of coverage. Table 1 provides information on trial dates corresponding with method of application. Selection of aircraft swath width and release height was based upon pre-test modeling (Rafferty et al. 1980).

[1]Observations by Larry Barber, Neil Overgaard and Julie Weatherby.

[2]This objective was reported on by Rafferty et al. 1981

Table 1.–Trial Summary, Withlacoochee State Seed Orchard, Florida, February 1980.

Trial	Time	Date	Type Applicator	Tank Mix[3]	Remarks
1	1554	2-13	Stearman		80 gal. sprayed
2	1008	2-15	Stearman		80 gal. sprayed No tree sampling
3	1507	2-15	Stearman		77 gal. sprayed Needle sampled
4	1718	2-15	FMC speed sprayer[1]		
5	1214	2-16	Stearman	with manganese sulfate	83 gal. sprayed Mylar sampling
6	1633	2-16	Stearman	with manganese sulfate	No mylar sampling
7	0942	2-18	Stearman	with manganese sulfate	Mylar sampling Spray system malfunction; only 15 gal. sprayed[4]
8	0734	2-19	Stearman		100 gal. sprayed
9	1557	2-19	Orchard sprayer[2]		
10	1707	2-19	Hughes 500C	with manganese sulfate	Mylar sampling
11	0748	2-20	Hughes 500C		
12	1043	2-20	Hughes 500C		
13	1757	2-20	Hughes 500C		
14	0749	2-21	Hughes 500C		No Nalco Trol
15	1110	2-21	FMC speed sprayer[1]		
16	1400	2-21	Orchard sprayer[2]		
17	1509	2-21	Orchard sprayer[2]		
18	0800	2-22	Orchard sprayer[2]		

1. FMC ground sprayer Md. LV 650.
2. Bean-type orchard sprayer mounted on stake body truck.
3. Unless otherwise noted, tank mix consisted of water, 4.5 oz. Rhodamine liquid BX dye per 100 gallons, and 5 oz. Nalco Trol per 100 gallons. Manganese sulfate (technical grade) was mixed at rate of 10 pounds per 100 gallons.
4. Spray pump malfunctioned.

METHOD

Site Description:

A 1/4 x 1/2 mile area within the Withlacoochee State Seed Orchard, containing an equal number of slash pine and Ocala sand pine, was selected as the demonstration site. The orchard is located a few miles north and west from the intersection of Highway 98 and Interstate 75 near Brooksville, Florida. The surrounding terrain is gently rolling, with elevations varying between 50 and 150 feet (15.2 and 46 meters) above mean sea-level, within 1 mile (1.61 kilometers) from the spray trial site, and a maximum elevation of 261 feet (80 meters) occurring at Munden Hill, 3 miles (4.8 kilometers) west-southwest from the spray trial site. The orchard contains stands of slash pine and Ocala sand pine. For the purposes of the spray trials, an area on the east side of the orchard, containing relatively uniform stands of slash and Ocala sand pine, was selected. Figure 1 is a schematic diagram showing portions of the demonstration area. Trees are every 15 feet (4.5 meters) in north-south rows, separated by a distance of 30 feet (9.1 meters). As shown in the figure, slash pine area is north of the service road, and Ocala sand pine is south of the road. The locations of the sample trees within which detailed deposition measurements were made are indicated by the numbers 1 through 12. Eight of the sample trees were located in the slash pine orchard, and four were located in the more dense Ocala sand pine orchard. A limited survey of the trees in the vicinity of the sample trees in the slash pine was made to locate undersized and missing trees. In Figure 1, the larger, open circles represent typical trees, and the smaller, open circles represent undersized or thinly branched trees. The absence of a tree is shown by a cross symbol (+). The rows of trees in every case extended about 1,200 feet (366 meters) to the north and south of the service road shown in the diagram. Tree dimensions are given in Table 2.

Meteorological Measurements:

Meteorological measurements were made on a 52-foot (16 meter) tower located on tree row number 13 at the position shown in Figure 1. MRI Vectorvanes were mounted at heights of 6.6 and 52.5 feet (2 and 16 meters) on the meteorological tower. The Vectorvanes measured azimuth and vertical wind directions and wind speed, which were recorded on Esterline Angus strip-chart recorders located at the base of the tower. A Climatronics Electronic Weather Station was used to measure and record azimuth wind direction and wind speed at a height of 6.6 feet (2 meters), at a position in an open field about 1,480 feet (450 meters) west of the tree row number 1, and about 66 feet (20 meters) south of the service road. Wind direction, wind speed, temperature, and relative humidity measurements were made to heights of 230 feet (70 meters) during most trials using a Tethersonde. The Tethersonde was located about 810 feet (247 meters) west of tree row number 1 and 141 feet (43 meters) south of the service road in a small, open area. Meteorological data recorded for each trial is provided in Table 3.

Application:

1. Aircraft - A Stearman bi-plane (Figure 2), modified for agricultural spraying, and a Hughes 500C (Figure 3a, 3b) were used in this project. Table 4 provides aircraft and application parameters. The spray boom was mounted immediately aft of the lower wing on the Stearman. The spray boom on the Hughes 500C helicopter was mounted a few feet below the fuselage, about midway between the front and rear landing skid struts. Spray was applied between rows 2 and 11 (Table 5).
2. Ground sprayers - Two models of ground sprayers were used. One was an FMC speed spray Md. LV 650 loaned to the project by FMC. The other sprayer belonged to the Withlacoochee Orchard. It was an older, Bean-type, 500-gallon capacity unit, with no identification plate. It was mounted on the bed of a stake body truck.

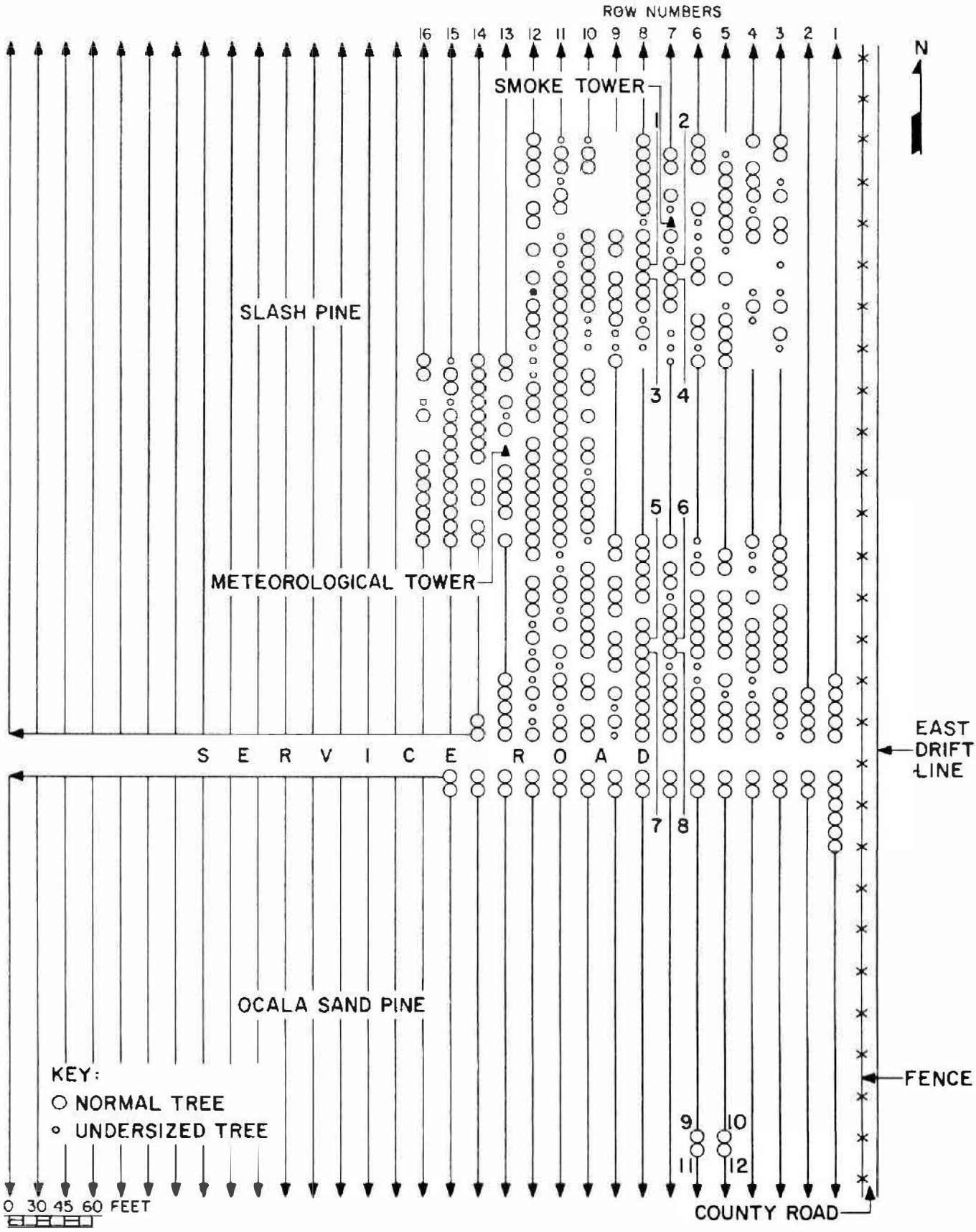


Figure 1. Diagram of a portion of the Withlacoochee State Seed Orchard used during the spray trials. The map shows details of the tree inventory in the sampling areas and near the meteorological tower in the slash pine. The sampling trees are indicated by the numbers 1 through 12.

Table 2.-Sample Tree Dimensions, Withlacoochee State Seed Orchard Project, February 1980.

Tree Species	Tree No.	Circumference	Height
Slash Pine	1	22"	40'
	2	28"	40'7"
	3	33"	45'5"
	4	30"	45'2"
	5	21.75"	41'
	6	36-1/2"	49'7"
	7	36"	41'2"
	8	27"	40'7"
	13	29.5"	44'4"
	14	27.25"	41'9"
	15	29.75"	39'9"
	16	31.75"	45'6"
Sand Pine	9	38.5"	50'
	10	38"	44'3"
	11	37.5"	42'2"
	12	38.75"	45'6"

Table 3.-Meteorological data recorded at spray time application, Withlacoochee State Orchard Project, February 1980.

			Winds (16 meters)	
Trial	Temp. (°C)	Relative Humidity (%)	Speed (mps)	Direction (∘)
1	12.3	33	2.77	354
2	14.4*	100*	1.02	23
3	19.4	74	1.10	20
4	20.0	70	0.7**	26**
5	21.2	67	3.15	214
6	25.0	52	4.21	256
7	8.5	68	6.20	33
8	10.4	95	1.79	354
9	No data collected for this trial.			
10	20.6	55	1.76	360
11	7.0	95	0.94	305
12	19.9	49	1.63	198
13	18.3*	61*	1.90	265
14	14.4	95	0.3**	197**
15	25.0*	56*	No data.	
16	25.0*	49*	No data.	

*Measurement taken at tower location.

**Wind measurements taken by Tethersonde; others at the meteorological tower (Fig. 1).

Figure 2. Pre-1940 Stearman, modified as an agricultural spray aircraft - Withlacoochee State Seed Orchard Project, 1980.

Figure 3a, 3b - Hughes 500C helicopter with mobile landing platform, which also serves as a nurse rig - Withlacoochee State Seed Orchard Project, 1980.

Table 4.–Aircraft and application parameters, Withlacoochee State Seed Orchard Project, February 1980.

Parameter	Stearman	Hughes 500C Helicopter
Aircraft Weight (lbs.)	3093.2	2545.4
Wing or Rotor Span (feet)	37.6	25.84
Speed (mph)	90	25
Spray Altitude Above Canopy (feet)[1]	5	5
Swath Width (feet)	30	30
Nozzle Type and Size[2]	D6-46	D2-45
Nozzle Orientation	down back 30°	straight back
Number of Nozzles	27	22
Boom Pressure (psig)	40	40
Application Rate (gpa)	5	5

1. Trials 1, 2, and 3 were 20 feet above canopy; other trials were 5 feet above canopy.
2. Manufactured by Spraying Systems Co.

Table 5.–Swaths by trial and tree row number; all swaths began on a south to north orientation over south to north tree rows. Withlacoochee State Seed Orchard, February 1980.

	Swaths/Tree Row									
Trial	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	7-8	7	5-6	4-5	3-4	2-3	1-2			
2	10-11	9-10	8-9	7-8	6-7	5-6	4-5			
3	10	9	8	7	6	5	4	3		
5	4-5	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	
6	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	
7	9-10	8-9	7-8	6-7	5-6	4-5	3-4	2-3	1-2	
10	10	10	9	8	7	6	5	4	3	2
11	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	
12	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	
13	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	
14	10	9	8	7	6	5	4	3	2	

Sampling:

Deposition sampling was made at the canopy top, at three levels in the tree crown, and on the orchard floor. Cylindrical samplers (aluminum soft-drink cans) were wrapped with Kromekote card material and with a 2-1/2 inch disc of the same material covering the top of the can. On trials 5, 7, and 10, cylindrical samplers wrapped with Mylar were positioned next to the Kromekote wrapped cans**(Table 6).**

At the top of the canopy, cylindrical samplers were suspended from a line stretched east-west across the tree rows at the position of the sampling trees. As shown in Figures 4 and 5 by the dotted lines, the canopy sampling lines extended one row east and west of the sample trees, and the cans were suspended at intervals of 6 feet (1.8 meters) along each line. The Kromekote-wrapped cans were placed also within the canopy on the sampling trees in the upper crown, midcrown, and in the lower crown at the four cardinal directions (Fig. 6) for a total of 12 cans per sampling tree. In each case, the cans were suspended from the ends of branches.

Ground-level measurements were made using Kromekote cards in plastic holders. Ground-sampling lines were placed beneath the sampling trees, as shown in Figure 4 by the solid lines, and extended two tree rows east and west of the sample trees. Cards were placed at intervals of 3 feet (0.9 meters) along these ground-sampling lines. Ground measurements using the Kromekote cards were also made along the middle of the service road between the slash pine and Ocala sand pine stands at 10-foot (3-meter) intervals. The service road sampling line began at row 1 in Figure 4 and extended westward for about 650 feet (198 meters).

Manganese sulfate tracer was added to the aircraft tank mix on Trials 5, 6, 7, and 10. By use of an atomic absorption technique, estimates of mass deposition were made. Mylar sheeting and Kromekote cards were used for subsequent mass analysis at selected locations in the ground-sampling network, on all tree cylindrical samplers at 6-foot (1.8 meter) intervals along the canopy lines, and at every other sampling location on the drift sampling lines for these trials.

The Kromekote cards were analyzed on the University of California Quantimet and the results evaluated by the FS Automatic Spot Counting and Sizing Computer program (ASCAS), Young et al. 1977.

Additionally, on Trial 3, needles were collected from both slash and Ocala sand pine to determine number of droplets per centimeter length of needle**(Figure 7).**

The two spread factor equations used to analyze Kromekote card data on the ASCAS program were as follows:

1. *Tank Mix* = water + Rhodamine

   y = aerodynamic drop size

   x = stain size on Kromekote paper

   $$y = \frac{x + 19.32}{1.81}$$

2. Tank Mix = water + Rhodamine + Nalco Trol

   $y = -93.421157 + 0.6775432x - 0.000051x^2$

Table 6.-Dimensions of samplers, Withlacoochee State Seed Orchard Project, February 1980.

Sampler	Dimensions (inches)
Cylindrical (can) sampler	
sides (Kromekote & Mylar)	4-1/4 x 8-3/16
top (Kromekote)	2-1/2 diameter disc
top (Mylar)	2-1/2 x 2-1/2
Kromekote card - surface exposed in holder	6-11/16 x 4-5/16
Mylar sheet - surface exposed in holder	6-11/16 x 4-5/16

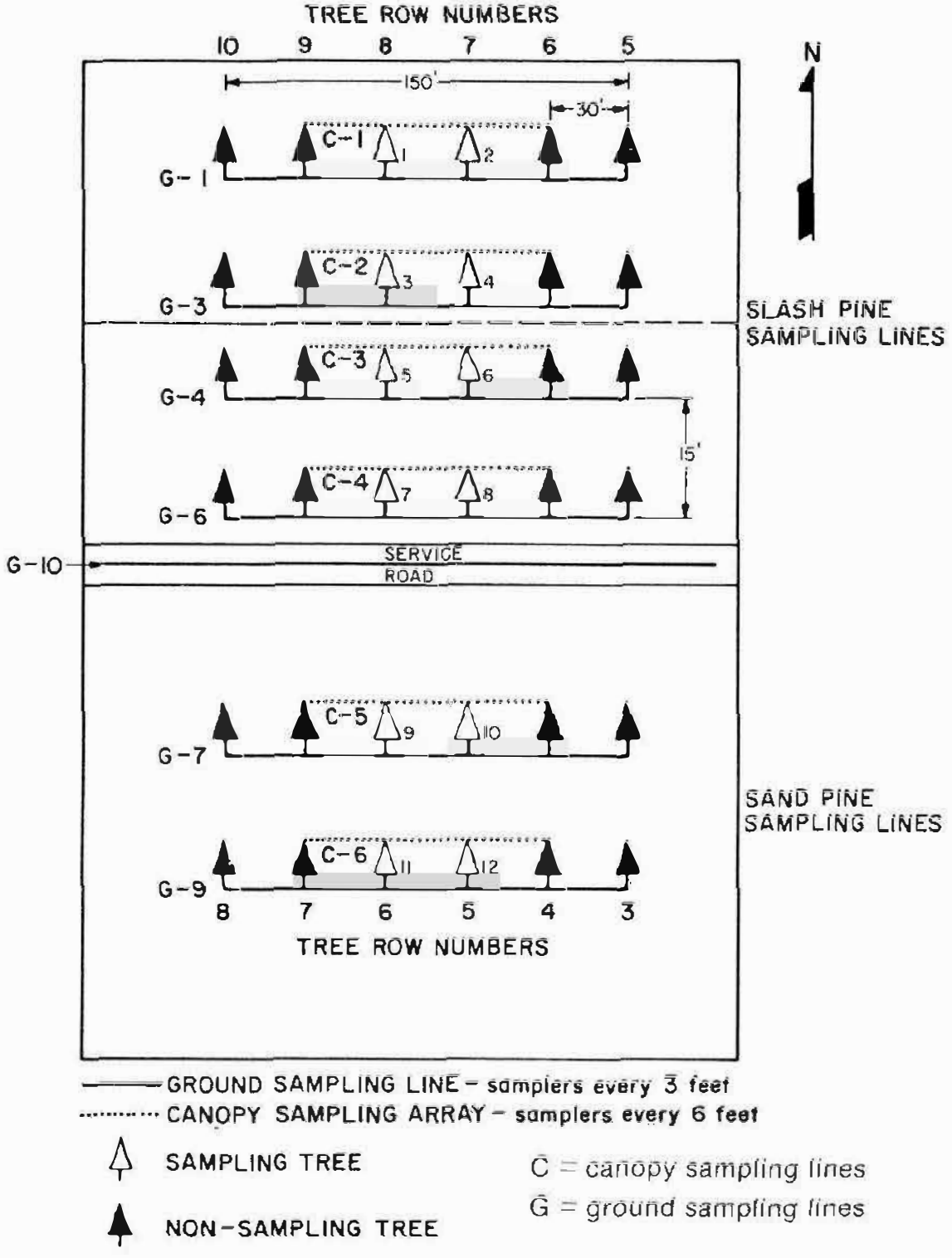
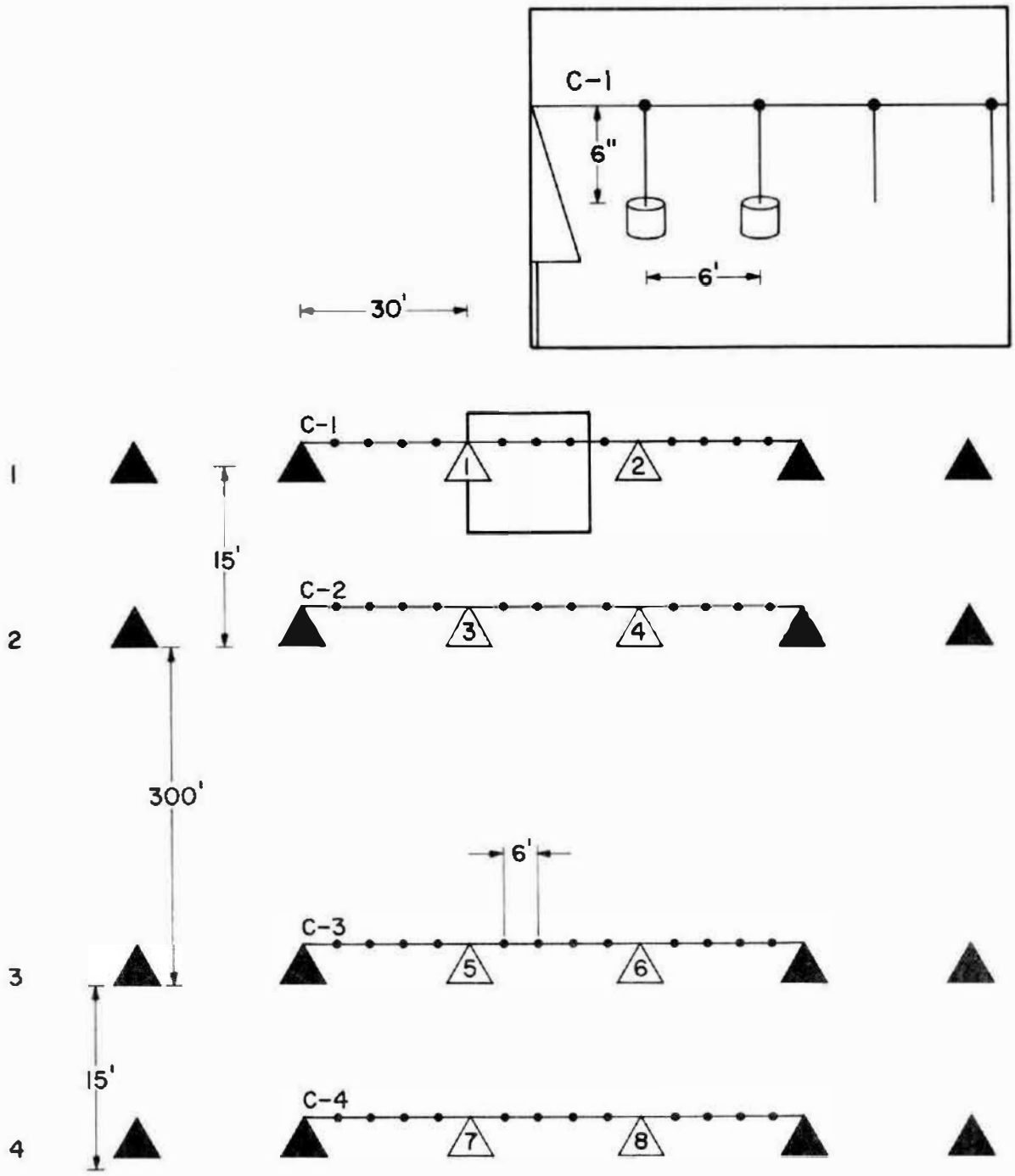


Figure 4. Sampling array for Withlacoochee State Seed Orchard trials, Florida, 1980.



LEGEND

sampling tree

non-sampling tree

cylindrical sampler

canopy sampling line

C-1 to C-4 canopy sampling line (C-5, C-6 not shown)

1 to 4 ground sampling lines

Figure 5. Canopy sampling diagram for cylindrical sampling, Withlacoochee seed orchard project, 1980.

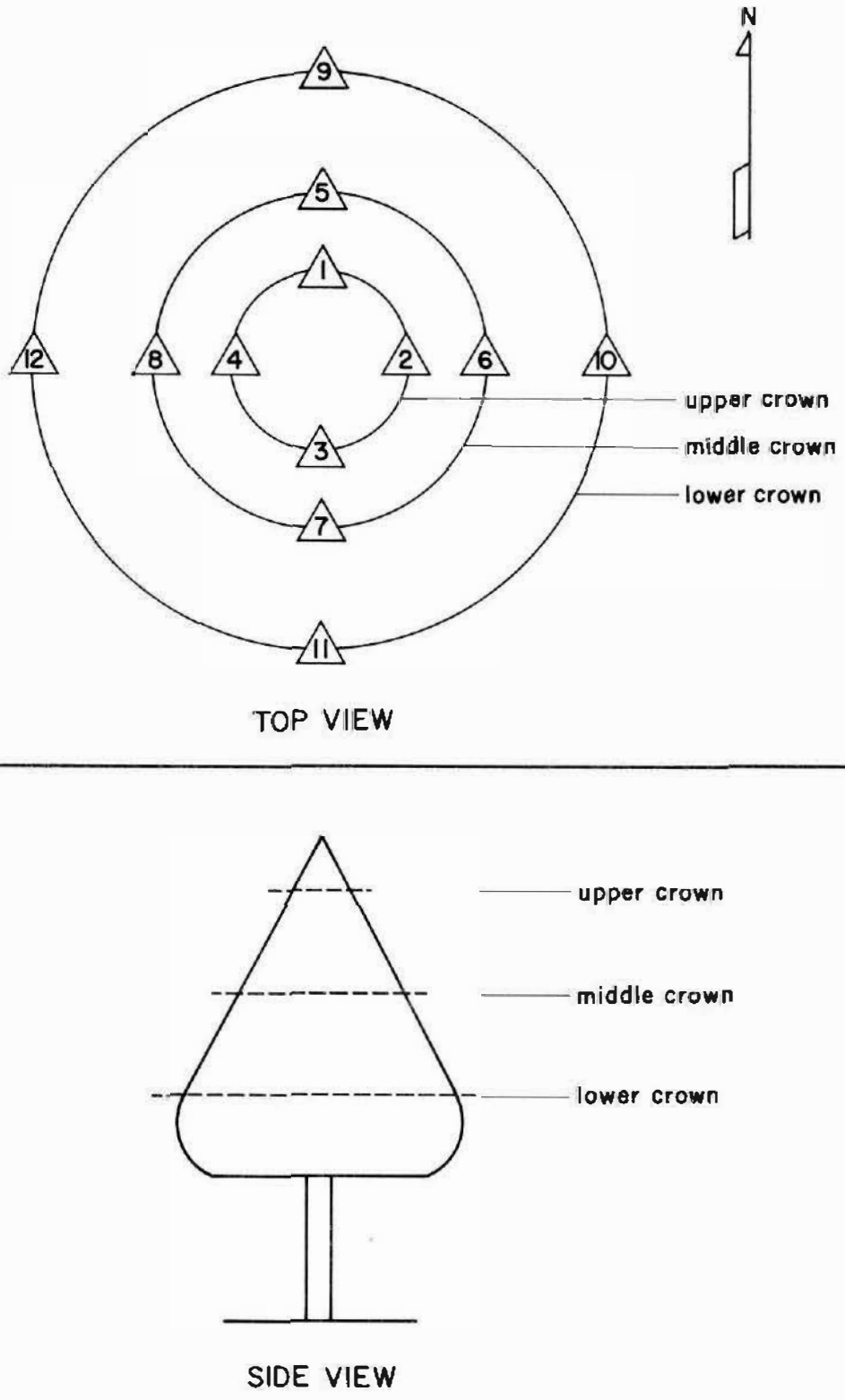


Figure 6. Tree sampling, cylindrical sampling in designated sample trees, Withlacoochee State Seed Orchard Project, 1980.

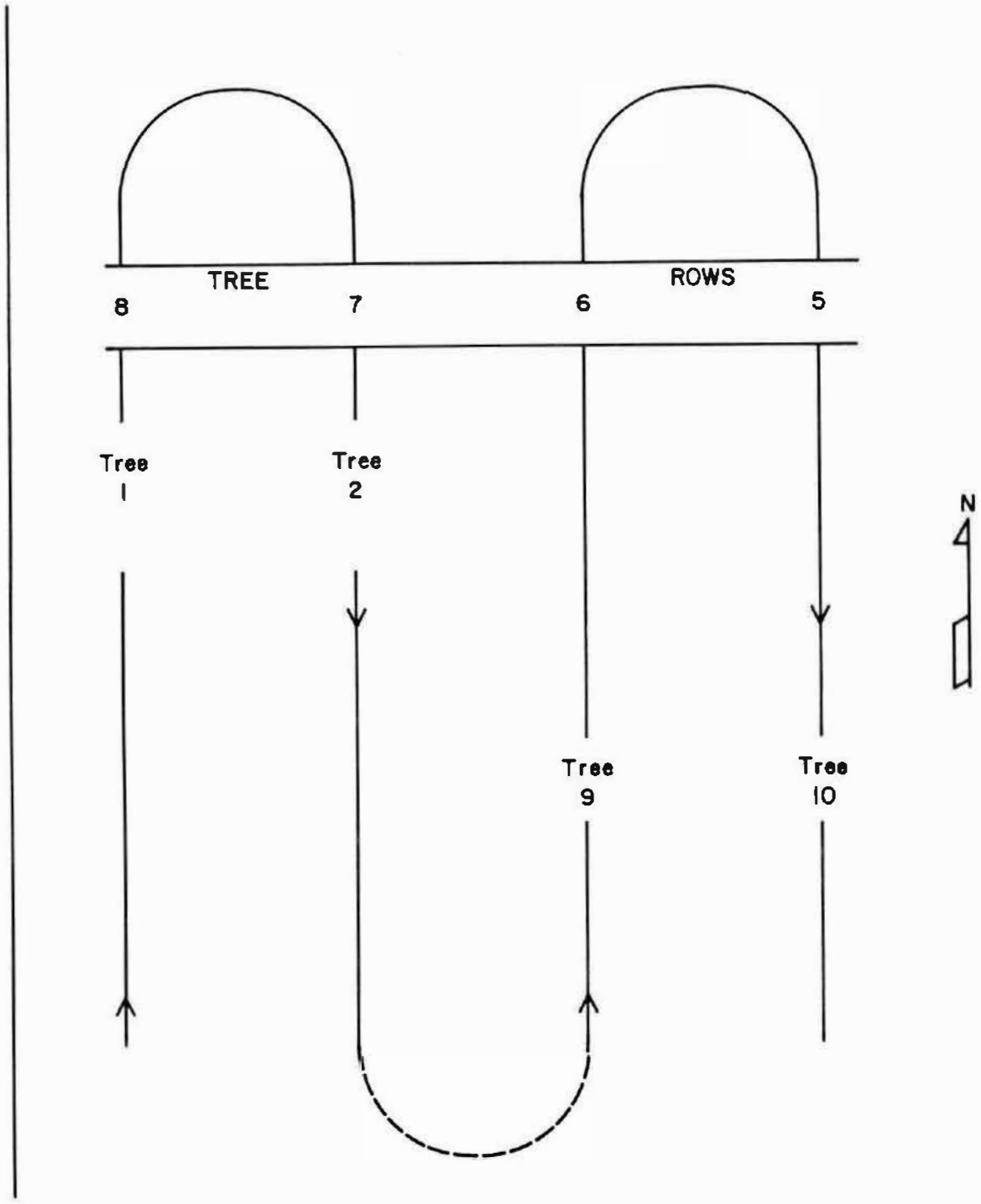


Figure 7
Direction of applying spray to slash pine trees 1 and 2 on rows 8 and 7, and to Ocala sand pine trees 9 and 10 on rows 6 and 5 for needle study, Trial 3, Withlacoochee State Seed Orchard Project, 1980.

RESULTS

Results are subdivided into five categories. For clarification purposes, some methodology is discussed throughout this section. Supplemental information on flight information is provided in Appendix A.

1. Fixed-wing vs. rotary aircraft application.
   a. Canopy penetration.
   b. Deposition in crown, Manganese sulfate method.
   c. Deposition in crown, Kromekote card method.
   d. Deposition top of canopy, Kromekote card method.
   e. Impaction of droplets on vertical surface of cylindrical samplers.
   f. Atomization.
2. Deposition of droplets on slash pine and Ocala sand pine foliage.
3. Ground sprayer tests.
4. Spray modeling using the FS CBG forest spray model.
5. Drift evaluations.
   a. Drift along orchard perimeter.
      1. Kromekote card sampling.
      2. Mylar sampling.
   b. Special drift study.

Fixed-wing vs Rotary Aircraft Application:

Canopy penetration: The penetration of spray droplets into the canopy and to the orchard floor was evaluated by plotting spray droplets observed on the orchard floor to that observed above the canopy. Plots of this analysis are provided in Appendix B. The plots for the Stearman and Hughes 500C show that a similar droplet spectrum penetrated the canopy for both aircraft. Consistent with previous forest spraying observations, the smaller droplets penetrate the forest canopy more readily, on a percent basis of total droplets, than do the larger droplets. The Kromekote card data (Table 7) show that more spray penetrated the canopy and deposited on the orchard floor on the Stearman trials as compared to the Hughes 500C trials. This would suggest that the Hughes 500C deposited more spray in the tree crowns than did the Stearman. This observation is supported in subsequent discussions. Canopy penetration on the Withlacoochee project is discussed in detail by Rafferty et al. 1981.

Table 7 - Percent penetration of the spray through the canopy to the ground, based upon recoveries at the canopy line and on the ground lines, Withlacoochee State Seed Orchard Project, February 1980.

Trial	Kromekote Card Data (Drop/cm²)
2 Stearman	29%
3 Stearman	22%
5 Stearman	61%
6 Stearman	27%
7 Stearman	18%
Mean	31.4%
10 Hughes 500C	12%
11 Hughes 500C	18%
12 Hughes 500C	11%
13 Hughes 500C	15%
14 Hughes 500C	35%
Mean	18.2 %

Deposition in the crown, manganese sulfate method: Deposition in the tree crown was sampled by cylindrical samplers covered with Mylar. Manganese sulfate ($MnSO_4$) tracer was added to the tank mix at the rate of 10 pounds per 100 gallons. In the laboratory, it was washed from the Mylar and assayed by atomic absorption for $MnSO_4$. Results of the three trials, in which $MnSO_4$ was assayed, are illustrated in Tables 8 and 9 and Appendix C.

No conclusions can be made about $MnSO_4$ recoveries between the two aircraft, as only three $MnSO_4$ trials were assayed. It is particularly interesting to note, however, (Tables 8 and 9) that a significant amount of the $MnSO_4$ tracer was unaccounted for sampling line, which was the index sample. This high percent of unaccounted material may be due, in part, to decreasing air velocities, collection efficiencies of the sampler, and scavenging affect of the foliage. Although this high loss occurred in the crown of both species, the affect was more pronounced in the Ocala sand pine, a more densely foliated tree. Dense foliage would tend to impede the downward air velocity and to scavenge droplets before they deposited on the samplers, particularly the lower level samplers.

Deposition in the crown, Kromekote card method: Kromekote cards also were used on the canopy line and in the crown to obtain deposition data. Kromekote paper was placed on the top of cylindrical samplers and positioned adjacent to the Mylar samplers.

Table 8.-Percent loss of spray, based upon manganese sulfate tracer method, at 3 crown levels in slash pine relative to spray recovered at canopy line positioned 5 feet below spray aircraft, Withlacoochee State Seed Orchard Project, February 1980.

Trial	Tree No.	Mean Recovery $MnSO_4$ at Crown Levels (Micrograms)		Percent Loss/Distance Loss[1] (%)	Distance (feet)[2]
5	1	Canopy top	199	---	---
		Upper crown	49	75	3
		Middle crown	32	84	11
		Lower crown	20	90	19
7	1	Canopy top	46	--	--
		Upper crown	15	63	3
		Middle crown	15	63	11
		Lower crown	10	88	19
10	1	Canopy top	105	--	--
		Upper crown	34	68	3
		Middle crown	40	62	11
		Lower crown	24	77	19

1. Vertical distance between canopy sample line and samples at each of 3 crown levels.
2. Percent determined from ratio of material at the respective crown level to that at the canopy line.

Trials 5 and 7 were Stearman trials, and 10 was a Hughes 500C trial.

Table 9.--Percent loss of spray, based upon manganese sulfate tracer method, at 3 crown levels in Ocala sand pine, relative to spray recovered at canopy line positioned 5 feet below spray aircraft, Withlacoochee State Seed Orchard Project, February 1980.

Trial	Tree No.	Mean Recovery MnSO[4] at Crown Levels (Micrograms)		Percent Loss/Distance Loss[1] (%)	Distance (feet)[2]
5	12	Canopy top	194	----	----
		Upper crown	32	83	5.5
		Middle crown	14	93	11.6
		Lower crown	10	95	21.5
7	12	Canopy top	32	--	--
		Upper crown	8	75	5.5
		Middle crown	6	81	11.6
		Lower crown	3	91	21.5
10	12	Canopy top	96	--	--
		Upper crown	17	82	5.5
		Middle crown	14	85	11.6
		Lower crown	14	85	21.5

1. Vertical distance between canopy sample line and samples at each of 3 crown levels.
2. Percent determined from ratio of material at the respective crown level to that at the canopy line.

Performance of the two aircraft; i.e., the Stearman fixed-wing and the Hughes 500C helicopter, was compared also in terms of the quantity of droplets deposited and volume of spray material recovered, as measured from the canopy to the ground. Trial means on drops and volume for each aircraft are shown in Tables 10 and 11.

Two separate analyses were conducted. First, we compared the percentage of drops and percentage of volume at the six sampling locations (Tables 10 and 11) using the overall means from the six trials. A paired t-test (Steel and Torrie, 1960) was used. The null hypothesis tested was that there is no difference between the two types of aircraft. The alternative was that there is a difference. Using the same procedure, the second analysis was to determine if there is any difference between the two aircraft in the quantity of drops and in the actual volume recovered from the various sampling locations.

Table 10.-Droplets per cm recovered from Kromekote cards at various sampling locations for Stearman and Hughes 500C trials, Withlacoochee State Seed Orchard Project, February 1980.

Sampling Location	Trials 1, 2, 3, 5, 6 (Stearman)					Drops	Percent*
	1	2	3	5	6	Means	
Canopy	--	80	65	60	28	58	16
Tree							
Upper crown	--	--	119	136	80	112	31
Middle crown	--	--	106	107	60	91	25
Lower crown	--	--	89	57	32	59	16
Ground (orchard)	9	50	22	14	7	20	6
Ground (open)	15	36	19	14	19	21	6

Sampling Location	Trials 10-14 Hughes 500C)					Drops	Percent*
	10	11	12	13	14	Means	
Canopy	68	75	70	64	74	70	15
Tree							
Upper crown	121	156	106	115	122	124	26
Middle crown	93	145	138	102	126	121	25
Lower crown	78	124	104	79	116	100	21
Ground (orchard)	19	40	23	18	43	20	6
Ground (open)	24	48	27	36	34	34	7

*Percent of total drops recovered at six locations, rounded off to the nearest percent.

Table 11.-Volume (gallons per acre) recovered from Kromekote cards at various sampling locations for Stearman and Hughes 500C trials, Withlacoochee State Seed Orchard Project, February 1980.

Sampling Location	Trials 1, 2,3, 5, 6 (Stearman)					Volume	Percent*
	1	2	3	5	6	Means	
Canopy	--	6.91	5.73	15.52	3.46	7.905	23
Tree							
Upper crown	--	--	6.13	19.57	5.25	10.316	30
Middle crown	--	--	4.41	12.62	7.07	8.033	24
Lower crown	--	--	4.34	5.03	4.85	4.74	14
Ground (orchard)	0.51	2.02	1.26	1.63	0.94	1.326	4
Ground (open)	0.97	1.78	1.07	0.97	2.86	1.53	5

Sampling Location	Trials 10- 14 (Hugh es 500C)					Volume	Percent*
	10	11	12	13	14	*Means*	
Canopy	16.03	17.86	16.39	8.81	21.27	16.072	23
Tree							
Upper crown	23.54	18.29	15.12	14.09	18.08	17.824	25
Middle crown	16.25	17.39	17.03	10.42	18.23	15.864	23
Lower crown	11.04	10.67	15.88	5.05	15.02	11.532	16
Ground (orchard)	1.94	3.3	1.65	1.31	6.36	2.912	4
Ground (open)	3.45	6.16	2.86	2.68	14.40	5.91	8

*Percent of total volume recovered at six locations, rounded off to the nearest percent.

The 90 percent and 95 percent confidence intervals are provided as follows:

Confidence intervals for the analysis of mean difference.

$\bar{d}$	Mean Difference	Confidence Intervals 90%	95%
$\bar{d}$	(% of drops)	(-2.6, 2.6)	(-3.4, 3.4)
$\bar{d}$	(% of volume)	(-2.2, 2.2)	(-2.8, 2.8)
$\bar{d}$	(number of drops)	(-30.1, -8.8)	(-33.1, -5.9)
$\bar{d}$	(volume)	(-8.2, -3.8)	(-8.8, -3.2)

It is evident from the examination of these figures that at 0.05 and 0.10 there is no difference in the percent of drops and percent volume, since zero is included in the confidence intervals provided. However, for the number of drops and volume, the results suggest that there is a difference between the two aircraft. In fact, from Tables 10 and 11, the total number of drops per cm^2 recovered from all levels was 478 for the Hughes and 361 for the Stearman. The mean volume in gallons recovered in the canopy from the Hughes trials was 15.07 and for the Stearman trials only 7.70. Again, we point out that there was no difference between the two aircraft in regards to spray deposition in the crown on the basis of percent.

Deposition in top of canopy, Kromekote card method: The Kromekote card discs from the top of the cylindrical samplers were counted for numbers of droplets from duplicate sets of samples, canopy lines 1-2 and 5-6. The samplers stretched east-west across the tops of trees and were positioned at 6-foot spacings. There was reasonable consistency between pair samplers on the duplicated lines. The deposit along the canopy lines (Appendix D) was uneven, suggesting wind influences or the uneven dispersion pattern existing directly beneath spray aircraft. This sample line was only 5 feet below the aircraft's boom. In this short distance, there is insufficient time for dispersion of the spray droplets within the wake before the spray comes in contact with the sampler. There was no attempt to evaluate differences in deposition at the canopy top between the two aircraft. This is the first known set of data on spray captured 5 feet below a spray aircraft, and above a forest canopy which was obtained at sufficient distance above the ground as to preclude ground reflection influence. These data are important for inputs to the FSCBG spray model and helps to interpret spray interactions at the top of the crop canopies.

Impaction of droplets on vertical surfaces of cylindrical samplers: Coverage of the cylindrical sampler surfaces by the stained droplets was assessed on the basis of percent of the total surface area of the cylinder covered, following procedures described in Appendix E. Table 12 provides the calculated mean coverage of the sampler by trial and by aircraft type and sprayer. More of the sampler surface was covered by spray from the helicopter than by the Stearman. This is due partially to the wake

Table 12.-Summary of percent spray droplet coverage on cylindrical sampler's surface. Data obtained from Kromekote cards, Withlacoochee State Seed Orchard Project, 1980.

Trial	Sprayer	Tree Species	Mean Coverage
1	Stearman	Slash pine	64
		Sand pine	76
3	Stearman	Slash pine	74
		Sand pine	71
5	Stearman	Slash pine	30
		Sand pine	36
6	Stearman	Slash pine	66
		Sand pine	81
8	Stearman	Slash pine	63
10	Hughes 500C	Slash pine	34
		Sand pine	42
11	Hughes 500C	Slash pine	98
		Sand pine	96
12	Hughes 500C	Slash pine	97
		Sand pine	96
13	Hughes 500C	Slash pine	93
		Sand pine	93
14	Hughes 500C	Slash pine	95
		Sand pine	94
4	FMC Sprayer	Slash pine	94
9	Withlacoochee Orchard Sprayer	Slash pine	97
15	FMC Sprayer	Slash pine	94
16	Withlacoochee Orchard Sprayer	Slash pine	88

characteristics of helicopters. A Hughes 500C with a gross weight of 2,650 pounds and main rotor of 37.1 feet, traveling 25 mph, would displace air at about a 35° angle from the vertical (Appendix F). This air mass entrained with spray droplets would be traveling at a velocity of about 17 mph (Anonymous, 1966). As the helicopter speed is increased, the advantage of helicopter over fixed-wing diminishes because the wake angle increases. Most spray helicopters operate at speeds greater than 50 mph. This 50 mph speed would change the angle to about 10° and the velocity to about 10 mph, which more closely approximates air displacement of fixed-wing aircraft. Based upon these data, a helicopter flying at 25 mph would propel its wake downward and likely provide more coverage than a fixed-wing. Our data support this supposition. Coverage of the samplers from the ground sprayer trials was comparable to the helicopter trials even though the ground sprayers applied 20 times more spray.

The statistical analysis presented, henceforth, compares the performance of a Stearman (A_1) and a helicopter (A_2), utilizing field measurements of two dependent variables - quantity of drops per square centimeter deposited on Kromekote discs placed on the tops of cylinder samplers hung in trees, and percent coverage of Kromekote side-wrappings on these samplers. Performance was analyzed at three different factor levels relating to three physical levels in the tree crown - upper (L_1), middle (L_2), and lower (L_3) - and two different factor levels of tree type - slash pine (T_1) and Ocala sand pine (T_2). Data were gathered from four

trees for each type and from five trials for each aircraft type. Four samplers were hung at cardinal directions at each crown level. The mean drop quantities and mean percent coverages at each crown level were calculated and utilized as the observations in the analysis. The observations were submitted for analysis to the Rummage II Data Analysis, UC Davis Version I program on the University of California, Davis, Burroughs 7800 computer.

The performance comparison was first approached utilizing a multivariate analysis technique to determine if there were any significant differences between the main effects of the three factors (aircraft, crown level, tree type) or any significant interactions between the factors when both dependent variables were considered at the same time. The aircraft-tree type response curves were then plotted against the individual crown levels for each dependent variable (Figures A and B) to look further at the main effects and the three factor interactions. These data were next compared by univariate techniques to determine significant differences in main effects and significant interactions between the factors when each dependent variable was considered alone. Bonferroni 99 percent confidence intervals were used to perform multiple comparisons of the different factor levels to determine the best performance and most adequate coverage. The statistical model assumed in the univariate analysis is as follows:

$$Y_{ijkl} = \mu \ldots + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} + (\alpha\beta\gamma)_{ijk} + \varepsilon_{ijkl}$$

$i = 1, 2;\ j = 1, 2, 3;\ k = 1, 2;\ l = 1, \ldots, 20^*$

where: the dependent variable is either percent coverage or quantity of drops per square centimeter,

$\mu \ldots$ is a constant,

$\alpha_i, \beta_j, \gamma_k, (\alpha\beta)_{ij}, (\alpha\gamma)_{ik}, (\beta\gamma)_{jk}, (\alpha\beta\gamma)_{ijk}$ are constants subject to the restrictions $\Sigma\alpha_i = \Sigma\beta_j = \Sigma\gamma_k = \sum_i(\alpha\beta)_{ij} = \sum_j(\alpha\beta)_{ij} = \sum_i(\alpha\gamma)_{ik} = \sum_k(\alpha\gamma)_{ik} = \sum_j(\beta\gamma)_{jk} = \sum_k(\beta\gamma)_{jk} = \sum_i(\alpha\beta\gamma)_{ijk} = \sum_j(\alpha\beta\gamma)_{ijk} = \sum_k(\alpha\beta\gamma)_{ijk} = 0$

ε_{ijkl} are independent N $(0, \sigma^2)$

*Four observations were missing per crown level for one of the fixed-wing trials in the sand pine.

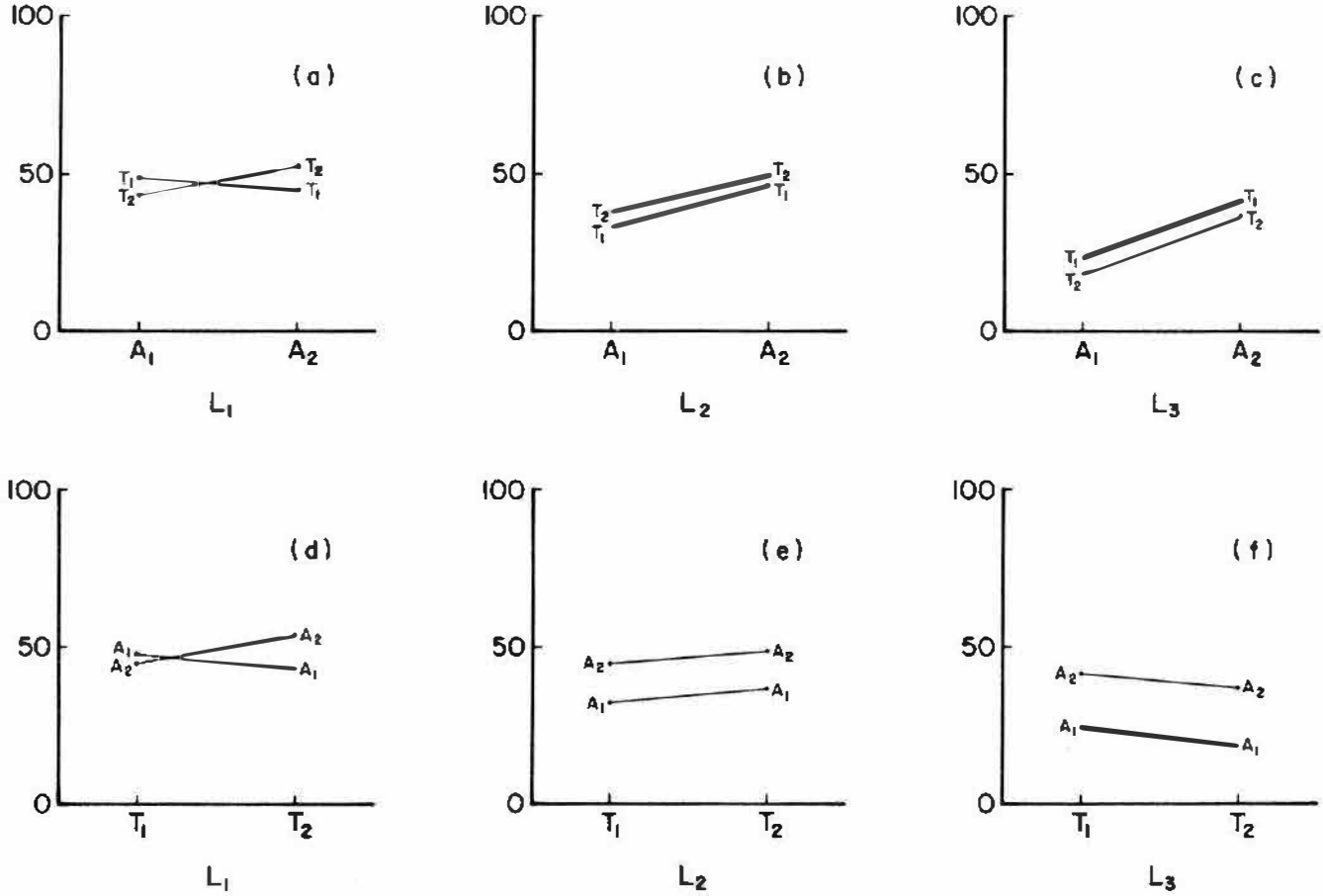


Figure A. – Response curves for dependent variable drops per square centimeter.

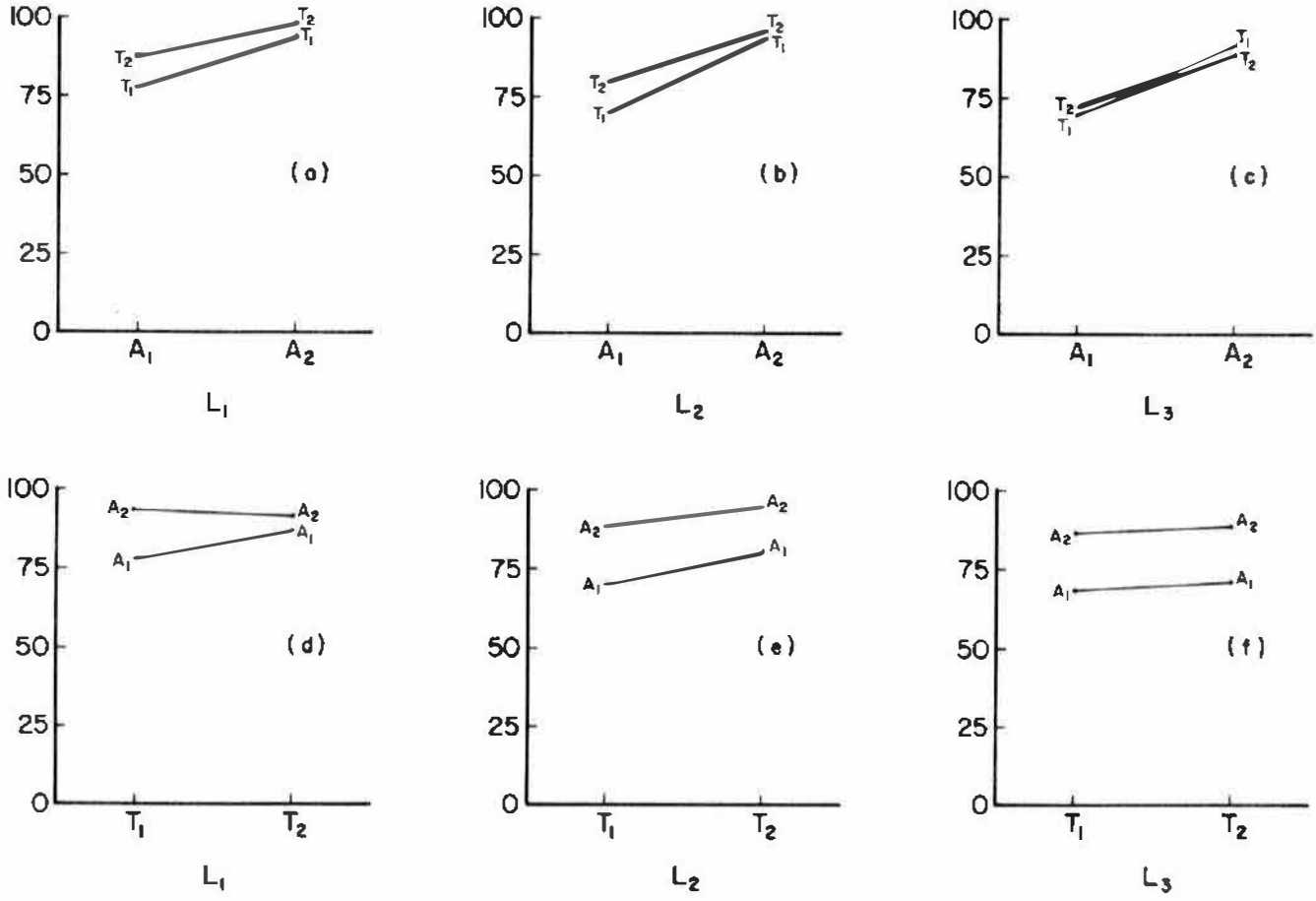


Figure B. – Response curves for dependent variable percent coverage.

The analysis of variance (ANOVA) Table A for the multivariate analysis shows a significant difference at the $\alpha = .01$ significance level between the two aircraft and also between the three crown levels. These signficant differences are determined from the F-ratio based on the F-distribution and related p-value, which is the smallest critical value at which the null hypotheses will be rejected. The table also shows a slight significant difference between the two tree types and a possible interaction between the two aircraft and the different tree types. Two factors are said to interact when the differences between the mean responses for the levels of one factor are not identical for all levels of the second factor.

From the plots (a-c), concerning drops per square centimeter (Figure A), there appear to be an interaction between aircraft and tree type in the upper crown level. This apparent interaction is not considered to have an effect on the analysis of the main effects of the factors, as it is minor in magnitude, and the other two crown levels demonstrate no such interaction. The minor interaction shown in Figure B (c), concerning percent coverage in the lower crown level, is also considered to be unimportant for the same reason. The plots a-c, Figure B (a-c), show no significant tree type effects, since the values for the dependent variable are not consistently higher for one particular tree type. Plots d-f, in both Figure A and Figure B, show the helicopter applications having greater values consistently, with the exception of the minor interaction in Figure B (d), which again creates no problem due to the reason given above.

From the univariate ANOVA Tables B and C for the dependent variables, percent coverage and drops per square centimeter, respectively, it is shown that significant differences at the $\alpha = .01$ significance level exist between the two aircraft and between the crown levels for both dependent variables. The slight significant difference between the tree types shown in Tables A, B, and C is due to the drops per square centimeter and not to the percent coverage. The possible aircraft-tree type interaction in Table A is shown by Table B to be due to the percent coverage.

As pointed out by the Bonferroni 99 percent confidence intervals in Table D, the helicopter deposited a greater number of drops per square centimeter on the top Kromekote discs and covered a greater percentage of the Kromekote side coverings of the cylinder samplers than the Stearman. The confidence intervals also show the upper crown level receiving a significantly greater quantity of spray for both dependent variables than the lower crown level, and the middle crown level receiving a slightly significantly greater quantity than the lower. No significant difference between the quantity received for the upper versus middle crown level can be determined at the $\alpha = .01$ significance level used in these intervals. A slightly greater percent coverage is, however, suggested for the Ocala sand pine over the slash pine.

In concluding, it is apparent throughout the analysis that the helicopter's performance is better than that of the fixed-wing aircraft, as judged by the two dependent variables utilized in this analysis and under the conditions present at the time the field trials were conducted. It is also apparent that the upper level of the tree crown receives a greater quantity of spray than the two lower levels for both aircraft. The other results mentioned are based on too weak a difference to make a definite conclusion without further trials.

Other factors, such as weather conditions should be considered as co-variates in an analysis of this type, to provide a more substantial and concrete stand to the results and conclusions drawn, herein.

Atomization: Atomization of the spray by trial and by aircraft type is given in Table 13. The data are from the cards positioned on the ground and in the open space between the slash and Ocala sand pine. The high VMD of 804 μm observed on Trial 14, in which no Nalco-Trol was used, is not understood. The target VMD for this project was 350 μm, and spray systems were characterized for 350 μm. This and the other higher VMD's on the field trials, as compared to the calibration trials, may have been the result of damp Kromekote cards, which increased droplet spreading. This, however, does not explain the high VMD observed on Trial 14 in which Nalco-Trol was not used. A boom pressure or mechanical problem may have developed in the spray system, causing the large drop sizes on Trial 14.

Table A.-Multivariate ANOVA. Withlacoochee State Seed Orchard, February 1980.

Source	d.f.	F-ratio	p-value
A	2	78.00	0.000
L	4	8.46	0.000
T	2	3.29	0.038
AT	2	5.38	0.005
AL	4	1.83	0.120
LT	4	1.17	0.319
ALT	4	0.47	0.755

Table B.-Univariate ANOVA for percent coverage.

Source	d.f.	F-ratio	p-value
A	1	183.80	0.000
L	2	11.44	0.000
T	1	5.98	0.015
AT	1	7.37	0.007
AL	2	2.87	0.059
LT	2	2.12	0.123
ALT	2	.32	0.729

Table C.-Univariate ANOVA for drops per square centimeter.

Source	d.f.	F-ratio	p-value
A	1	16.37	0.000
L	2	12.57	0.000
T	1	.02	0.874
AT	1	.53	0.468
AL	2	2.18	0.115
LT	2	.94	0.393
ALT	2	.55	0.578

A = Aircraft type
L = Level in tree crown
T = Tree type
AT = Interaction of aircraft type and tree type
AL = Interaction of aircraft type and level in tree crown
LT = Interaction of level in tree crown and tree type
ALT = Interaction of aircraft type, level in tree crown, and tree type.

Table D.-Bonferroni 99 percent confidence intervals. Withlacoochee State Seed Orchard, February, 1980.

Pairwise differences of estimated means	Quantity of drops	Percent coverage
A_1-A_2	-18.194 to -4.006	-20.995 to -14.09
L_1-L_2	-3.966 to 15.878	-0.666 to 8.384
L_1-L_3	6.919 to 26.763	3.297 to 12.947
L_2-L_3	0.962 to 20.806	0.862 to 8.787
T_1-T_2	-7.411 to 6.777	-6.904 to -0.005

Note:

A_1 = Stearman fixed-wing.
A_2 = Hughes 500C helicopter.
L_1 = Upper canopy.
L_2 = Middle canopy.
L_3 = Lower canopy.
T_1 = Slash pine.
T_2 = Sand pine.

Table 13.-Summary of droplet size data obtained from ground Kromekote cards in the open on line 10, Withlacoochee State Seed Orchard Project, February 1980.

Trial	Aircraft	Droplet Size Data (μm) mass median diameter	mass mean diameter	number median diameter	number mean	Remarks
1	Stearman	345	376	133	157	20' release
2	Stearman	405	435	74	113	" "
3	Stearman	352	377	117	142	" "
5	Stearman	572	605	107	165	
5	Stearman	475	494	146	177	5' release all
6	Stearman	572	605	107	165	other trials
7	Stearman	572	622	160	207	
10	Hughes 500C	525	555	130	175	
11	Hughes 500C	595	621	89	146	
12	Hughes 500C	483	508	117	158	
13	Hughes 500C	482	504	120	159	
14	Hughes 500C	804	831	202	268	No Nalco Trol[1] in tank mix

[1]Nalco Trol was used in the tank mix of all other trials.

Deposition and Impaction of droplets on slash pine and Ocala sand pine:

After the orchard was sprayed on Trial 3, needles were collected for examination and assessment. The collected foliage had been covered by plastic bags to prevent droplet contamination during Trial 1 and Trial 2. Application was as illustrated in Figure 7.

Two slash pines and two Ocala sample trees were identified as trees 1 and 2, and the Ocala sand pines were identified as trees 9 and 10, respectively (Figs. 1 and 4). The two species differed in physical appearance and size (Table 14). The Ocala sand pines were denser (Fig. 8) and contained more foliage than the slash pines (Fig. 9). Also, the needles on the Ocala sand pine were shorter than the slash pine needles.

After spray application, several fascicles were collected from each cardinal direction at three levels - upper crown, middle crown, and lower crown. This represented a total of 12 sampling positions per tree. In the laboratory, five needles were selected randomly from five different fascicles, which had been collected at each of the 12 sampling positions. This totaled 60 needles examined from each tree. The length of each needle was measured and the needles examined for presence of red stains. The slash pine needles were found to be over 20 cm in length, and the Ocala sand pine needles less than 10 cm.

Table 14.-Characteristics of trees selected for needle study, Withlacoochee State Seed orchard, February 1980.

Sample Tree	Type	Height	Upper Crown	Middle Crown	Lower Crown	DBH
1	Slash Pine	40'	37'	29'	21'	7.0"
2	Slash Pine	40'7"	37"	28'	21'	8.9"
9	Sand Pine	50'	46'	40'	33'	12.3"
10	Sand Pine	44'3"	41'	37'	30'	12.1"

Figure 8. – Aerial bucket truck positioned at south end of orchard. Orchard trees are Ocala sand pine. Personnel in background will serve as flagman. Personnel in bucket are facing northeast. Withlacoochee State Seed Orchard Project, 1980.

Figure 9. – Slash pine; view looking south at sample trees 1, 2, and 3 (white bands). Smoke is being released by NASA personnel to monitor dispersion by aircraft. Withlacoochee State Seed Orchard Project, 1980.

These data were analyzed by comparing the amount of drops observed at various crown levels for both slash pine and Ocala sand pine. Specifically, this was accomplished by estimating the number of drops observed from an equal number of needles per species, with consideration given to differences in needle length. For each sample tree and from the two different tree species, an analysis of mean differences was conducted using a two-sample t-test (two tail), Goldstein (1965).

A greater number of drops were found on the upper crown, as compared to the lower crown (Figs. 10a, b and 11a, b). This was significant at the 5 percent level and held true for all trees and for both species of trees. While this relationship is consistent between the lower and upper crowns, it does not hold for the other two combinations - lower to middle and middle to upper. These relationships, though not conclusive, tend to support our argument (Tables 15 and 16).

More drops were found in the crown of slash pine per centimeter of needle length than in the crown of sand pine (Table 17). The range of values for slash pine ranged from 3.36 to 17.69, and Ocala sand pine ranged from 0.45 to 1.78. The number of drops at any crown level for Ocala sand pine appears to be at least several orders of magnitude lower than that of slash pine. The Ocala sand pine contained more foliage; thus, there was more competition for drops in the Ocala sand pine compared to that of the less dense slash pine. Assuming a similar collection efficiency between slash and Ocala sand pine, one could argue that given the same number of spray drops, deposition density would, per linear length of needle, be less on the sand pine as compared to slash pine. This would result in less pesticide coverage on Ocala sand pine.

Table 15.-Significance of mean differences number of spray drops on needles at three crown levels within each sample tree for Ocala sand pine, Withlacoochee State Seed Orchard, February 1980.

Tree crown location of sample	Mean drops/cm length of needle	No. of needles per sample	t-value
	Tree 1		
Lower : middle	0.96 : 1.25	20	-1.549 (N.S.)
Lower : upper	0.96 : 1.78	20	-3.869**
Middle : upper	1.25 : 1.78	20	-2.489*
	Tree 2		
Lower : middle	0.45 : 1.32	20	-2.569*
Lower : upper	0.45 : 0.81	20	-2.692*
Middle : upper	1.32 : 0.81	20	1.462 (N.S.)

*Significant at 95% level.

**Significant at 99% level.

(N.S.) Not significant at 95% level or 99% level.

TREE NO: 1
SPECIES: Slash Pine
DIRECTION FLIGHT: South to North

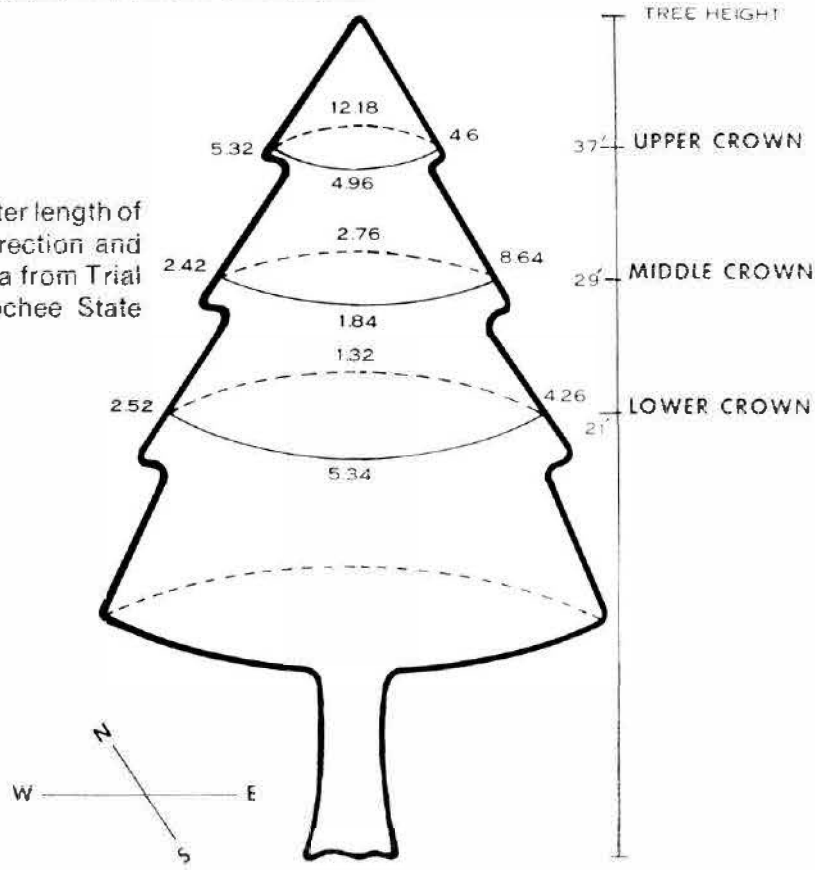
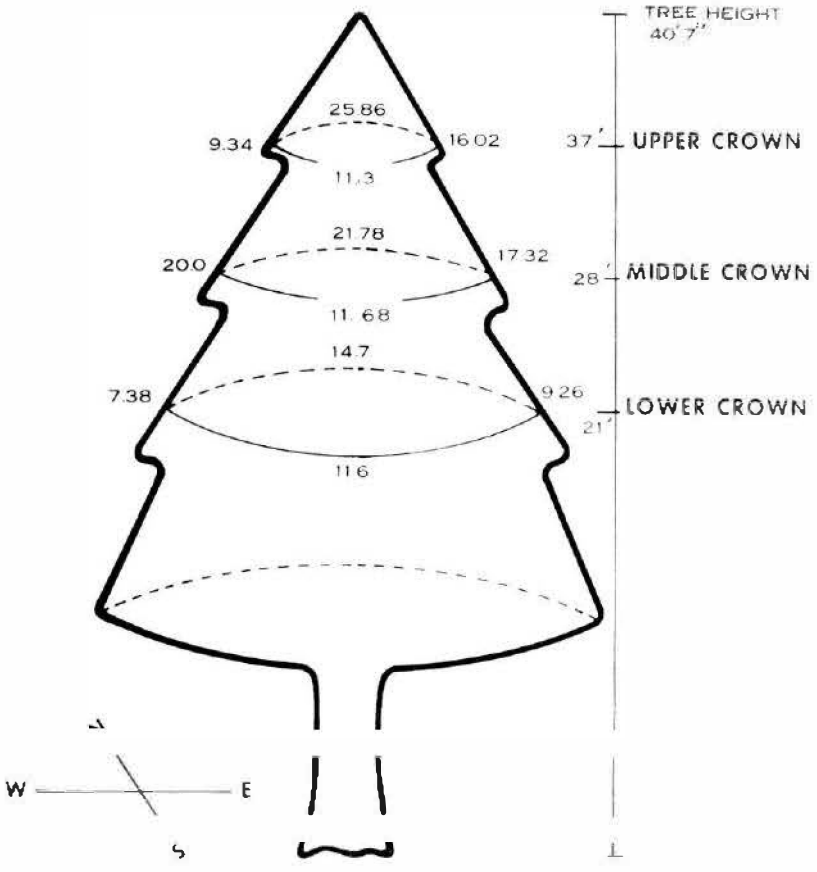


Figure 10a,b - Droplets per centimeter length of needle observed at each cardinal direction and three crown levels on slash pine. Data from Trial 3, Stearman application, Withlacoochee State Seed Orchard Project, 1980.

TREE NO: 2
SPECIES: Slash Pine
DIRECTION FLIGHT: North to South



TREE NO: 9
SPECIES: Sand Pine
DIRECTION FLIGHT: South to North

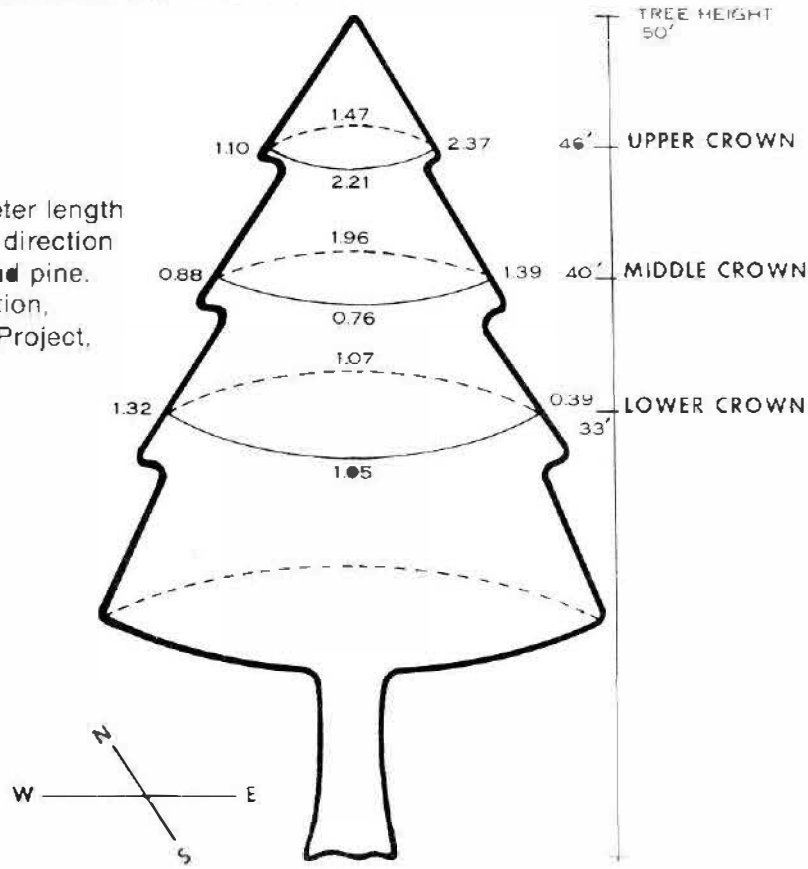


Figure 11a,b. – Droplets per centimeter length of needle observed at each cardinal direction and three crown levels on Ocala sand pine. Data from Trial 3, Stearman application, Withlacoochee State Seed Orchard Project, 1980.

TREE NO: 10
SPECIES: Sand Pine
DIRECTION FLIGHT: North to South

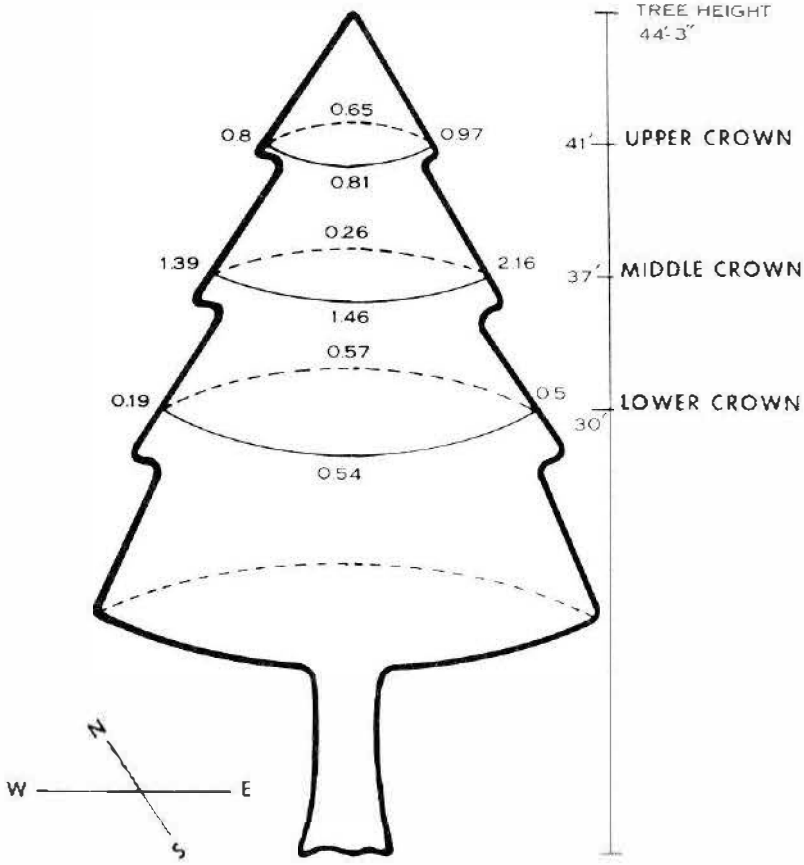


Table 16.-Significance of mean differences number of spray drops on needles at three crown levels within each sample tree for slash pine, Withlacoochee State Seed Orchard, February 1980.

Tree crown location of sample	Mean drops/cm length of needle	No. of needles per sample	t-value
	Tree 9		
Lower : middle	3.36 : 3.91	20	-0.687 (N.S.)
Lower : upper	3.36: 6.82	20	-3.579**
Middle : upper	3.91 : 6.82	20	-2.650*
	Tree 10		
Lower : middle	10.73 : 17.69	20	-4.397*
Lower : upper	10.73: 15.63	20	-2.519*
Middle : upper	17.69 : 15.63	20	0.946 (N.S.)

*Significant at 95% level.
**Significant at 99% level.
(N.S.) Not significant at 95% level or 99% level.

Table 17.-Summary data, mean number of drops per centimeter of needle length, Withlacoochee State Seed Orchard, February 1980.

Location	Slash Pine		Sand Pine	
	Tree 1	Tree 2	Tree 9	Tree 10
Upper crown	6.8	15.6	1.8	0.8
Middle crown	3.9	17.7	1.3	1.3
Lower crown	3.4	10.7	1.0	0.5

Application was at 46.76 litters per hectare by Stearman, flying 1.5 meters above the canopy, 9.1 meter lane separation, 78 knots forward speed, and using Spraying Systems D-6-46 hollow cone nozzles oriented back 30°.

It is noted also that data on needle deposition can be used to evaluate and to develop dose rates for aerial application. In seed and cone insect control it is important to cover with spray all plant tissue which insects may contact. Thus, this technique can be used as a complement to chemical assay.

Ground sprayer tests:

Two ground sprayers were evaluated on a qualitative basis primarily to check their potential for covering coniferous seed trees with spray. As described earlier, one was an FMC speed sprayer, Md. LV650, tractor towed, and the other a Bean type mounted on a flatbed truck. The FMC unit was used on Trials 4 and 15, and the Bean unit on Trials 9, 16, 17, and 18.

Prior to testing, the sprayers were cleaned, calibrated to apply 100 gallons per acre, and the nozzles positioned for optimum coverage. For maximum efficiency, both sprayers were operated to discharge the spray on one side only (Fig. 12); therefore, each side of the tree row was sprayed. These trials were restricted to the slash pine. Cylindrical samplers were positioned in the trees in the same manner as on the serial trials. Samplers were assessed qualitatively following procedures described in Appendix E. The coverage of the samplers by the ground sprayers (Table 12) was better than observed on the samplers from the Stearman trials, but about equal to the Hughes 500C trials. It is noteworthy that the ground sprayers were applying spray at 100 gallons per acre, while the aircraft were applying only 5 gallons per acre. Spray deposit cards placed on the ground beneath the sampled trees (on the ground sprayer trials) were too saturated by the spray for assessment. This clearly demonstrates the wastefulness and contamination which results from ground

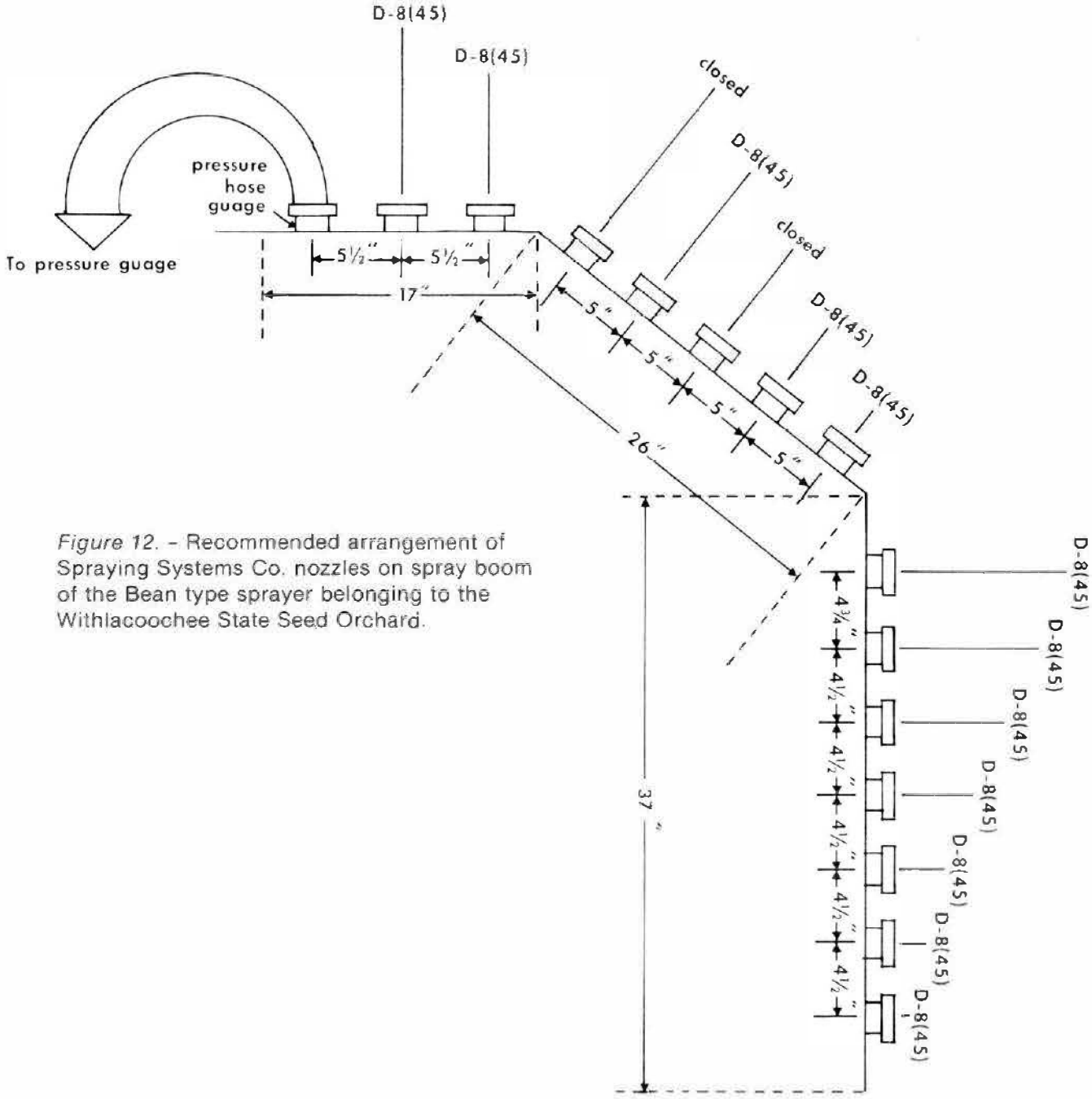


Figure 12. - Recommended arrangement of Spraying Systems Co. nozzles on spray boom of the Bean type sprayer belonging to the Withlacoochee State Seed Orchard.

application.

This test demonstrated that ground equipment in good operating condition can provide effective coverage of the trees. Prior to this test, there were some questions about ground sprayers reaching the upper crown of 50-foot trees. The two sprayers used on this test had no difficulty once the equipment was cleaned, calibrated, and the nozzles positioned properly. Factors to consider in selecting type of application (ground or aerial) are listed in Table 18.

There may be a greater potential for spray drift from ground spray operations than from aerial. Ware (1969) reported more drift from mist blowers when compared to aircraft. Field observations during the Withlacoochee trial further support Ware's conclusions.

Table 18.-Comparison of aerial to ground applications in seed orchards.

Aircraft	Factor	Ground Sprayers
Yes	Access to orchard under muddy conditions	?
No	Soil compaction	Yes
Yes	Spray during favorable weather	?[1]
Short	Time to treat orchard	Long
Less	Pesticide drift[2]	More (mist type)
Few	Orchard Manpower	Several
Low	Volume material per acre	10 to 20 times more
Less	Toxic material per acre	More
No[3]	Equipment depreciation, storage[3]	Yes
Less	Personnel exposure operating equipment	More

1. Favorable weather conditions for depositing spray in the tree crowns and minimizing spray drift. Ground sprayers often operate during unfavorable meteorological conditions in order to treat the entire orchard.

2. Ware et al. (1969)

3. Assume contractor aircraft.

Spray modeling using the Forest Service CBG forest spray model:

The results of this sub-study were reported by Rafferty et al. 1981:

"The Withlacoochee spray trials were planned and conducted as a pilot project. . to evaluate the feasibility of using aerial spray application techniques in the control of cone losses due to coneworm infestations in pine seed orchards. As part of the overall pilot project, deposition measurements were made at the orchard canopy top, within sample trees, and on the ground beneath the trees. These measurements were made for use in defining the effectiveness of the aerial spray application technique and to evaluate the potential usefulness of the Cramer-Barry-Grim (CBG) computerized model in the planning, conduct, and analysis of seed orchard spray projects."

Drift evaluations:

Drift was monitored along the orchard perimeter by using cylindrical and horizontal samplers. Additionally, a special drift study was conducted on February 20, 1980, over an open area at the Withlacoochee orchard.

Drift along orchard perimeter: Samplers were positioned 60 feet beyond the perimeter of the orchard trees to detect drift (Fig. 13). Sampling positions were numbered every 1 through 82 (Fig. 13). Mylar-wrapped cylinders were positioned on 5-foot stakes at each even numbered station (200 feet spacing) and a Kromekote card at each odd numbered station (200 feet spacing). Kromekote cards were placed on the ground at each station (100 feet spacing). The north and south drift lines were about 1,312 feet north and south of the service road - shown in Figure 13 - just beyond the end of the tree rows in the orchard. The west drift line was located about 1,312 feet west of tree row number 1. If the wind direction for a trial was from, for example, the southwest or south, samplers were placed along the north and east drift lines. The system used to number the samplers is shown in Figure 13.

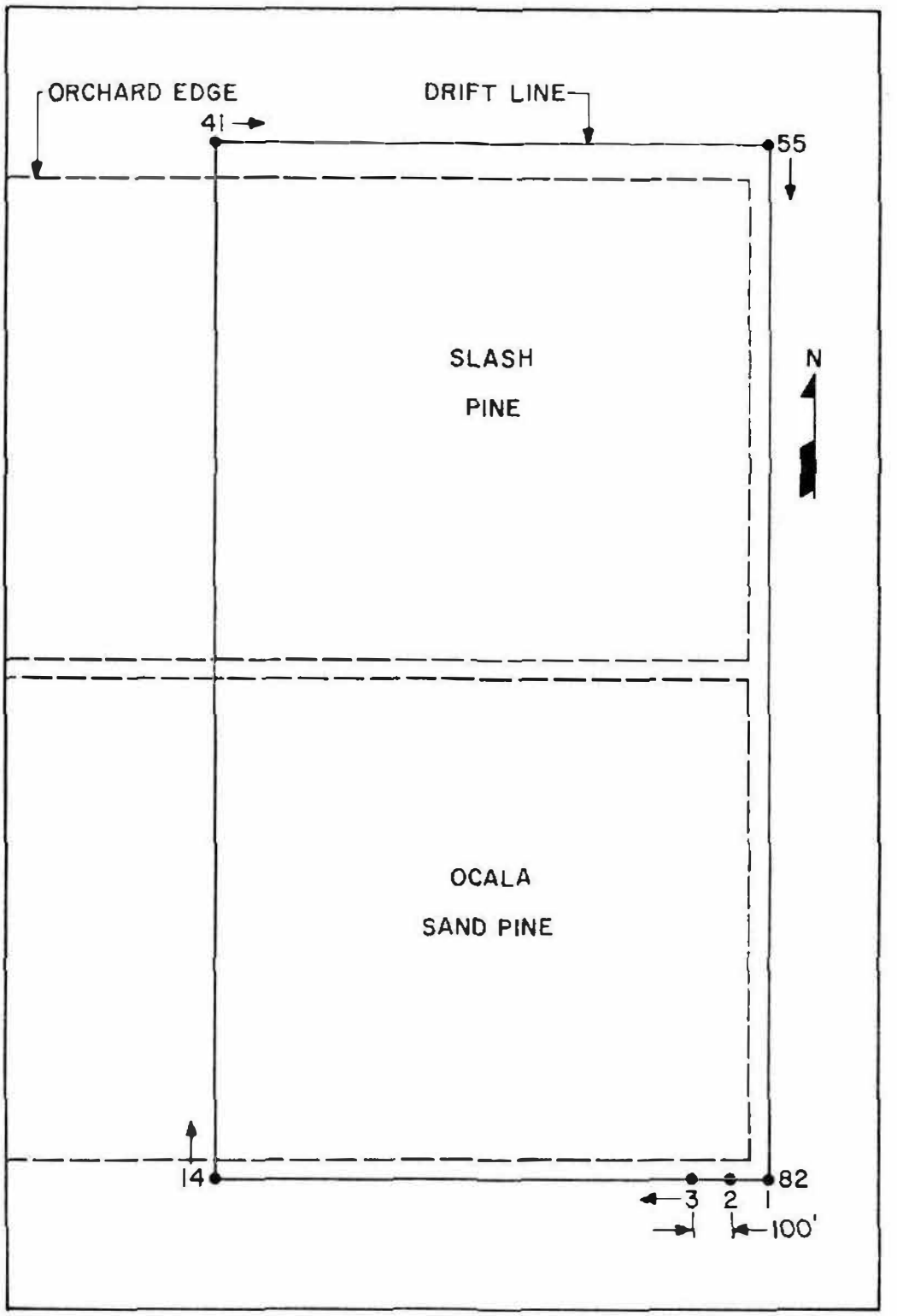


Figure 13 - Drift samplers numbering 1 through 82 positioned relative to spray block, Withlacoochie State Seed Orchard 1980.

Kromekote card drift sampling: It was apparent that the pilot's "turn on" and "turn off" points were within the 60-foot buffer, at the north and south ends of the orchard. Spray deposits were observed within the buffer strips. Based upon this observation, a buffer strip of at least 60 feet should be provided at the ends of orchards being treated by aircraft. Depending upon wind direction and other atmospheric conditions spray deposits should be expected within a 60-foot zone on the ends of spray blocks. An additional buffer distance is needed, depending upon wind speed and direction, to allow for drift.

The drift data, reported in Tables 19-22 for Trials 11-14, show that drift was confined generally within 105 feet of the treatment area.

Mylar drift sampling: Mylar samplers were assessed for presence of $MnSO^4$ salts. The cylindrical samplers were placed on stakes, and the horizontal samplers were positioned on the ground at the base of the stake. Results of these analyses are provided in Tables 23-28. The last column presents the recovery data in gallons of tank mix per acre, recalling that 5 gallons of tank mix was applied per acre. Examination of these data reveals only minimal drift occurred along the orchard perimeter. The highest recovery was 0.01245 gallons per acre or 11.65 micrograms per square meter. The sampler, from which these numbers were derived, was located approximately 60 feet from the nearest spray swath.

Table 19.-Drift data obtained on Kromekote cards from Trial 11, Withlacoochee State Seed Orchard Project, 1980.

Trial: 11
Date: 2/80
Time: 0748
Aircraft: Hughes 500C

Wind Speed: 0.94 mps.
Wind Direction: 305°

Sampler no./ distance downwind of spray line	Drops/cm² on Kromekote cards placed on ground	Drops/cm² on top Kromekote cans
67/105'	14.83	12.37
68/105'	10.85	--
69/105'	7.38	9.47
70/105'	6.69	--
71/105'	2.52	3.66
72/105'	5.81	--
73/105'	7.26	7.57
74/105'	5.93	--
75/105'	9.97	13.50
76/105'	7.00	--
77/105'	5.87	4.17
78/105'	4.92	--
79/105'	5.68	6.31
80/105'	4.86	--
81/105'	3.60	3.41

Table 20.–Drift data obtained on Kromekote cards from Trial 12, Withlacoochee State Seed Orchard Project, 1980.

Trial: 12
Date: 2/80
Time: 1043
Aircraft: Hughes 500C

Wind Speed: 1.53 mps.
Wind Direction: 198°

Sampler no./ distance downwind of spray line	Drops/cm² on Kromekote cards placed on ground	Drops/cm² on top Kromekote cans
55/105'	.63	.63
56/105'	.25	--
57/105'	.25	.50
58/105'	.19	--
59/105'	.38	--
60/105'	1.58	--
61/105'	.19	--
62/105'	.26	--
63/105'	.19	--
64/105'	1.07	--
79/105'	.82	.50
80/105'	.32	--
81/105'	.32	--

Table 21.-Drift data obtained on Kromekote cards from Trial 13, Withlacoochee State Seed Orchard Project, 1980.

Trial: 13
Date: 2/80
Time: 1757
Aircraft: Hughes 500C

Wind Speed: 1.9 mps.
Wind Direction: 265°

Sampler no./ distance downwind of spray line	Drops/cm² on Kromekote cards placed on ground	Drops/cm² Kromekote cans
55/105'	10.79	6.69
56/105'	--	--
57/105'	1.70	.63
58/105'	--	--
59/105'	--	8.84
60/105'	3.60	--
61/105'	2.02	.80
62/105'	1.70	--
63/105'	3.60	3.66
64/105'	5.55	--
65/105'	1.33	.76
66/105'	3.85	--
67/105'	3.22	2.02
68/105'	3.53	--
69/105'	1.70	1.77
70/105'	1.14	--
71/105'	--	.13
72/105'	1.39	--
73/105'	--	1.01
74/105'	1.33	--
75/105'	1.89	1.77
76/105'	.76	--
77/105'	.82	.50
78/105'	1.51	--
79/105'	--	3.28
80/105'	1.64	--
81/105'	1.89	1.51

Table 22.-Drift data obtained on Kromekote cards from Trial 14, Withlacoochee State Seed Orchard Project, 1980.

Trial: 14	**Wind Speed: 0.3 mps.**
Date: 2/80	**Wind Direction: 197°**
Time: 0749	
Aircraft: Hughes 500C	

Sampler no./ distance downwind of spray line	**Drops/cm² on Kromekote cards placed on ground**	**Drops/cm² on top Kromekote cans**
55/90'	6.63	4.67
56/90'	.88	--
57/90'	4.10	2.27
58/90'	7.32	--
59/90'	6.88	7.3260
60/90'	2.78	--
61/90'	6.12	9.34
62/90'	11.04	--
63/90'	3.41	4.4264
64/90'	.32	--
65/90'	.19	.88
66/90'	6.00	--
67/90'	4.86	2.40
68/90'	1.51	--

Table 23.- Trial 10 drift data; manganese sulfate recovered fro m Mylar sheets covering cylindrical samplers positioned vertically, or from Mylar sheets positioned horizontally on the ground, Withlacoochee State Seed Orchard Project, 1980.

Sampler[1] number	Distance downwind (ft)	Sampler type	Micrograms of[2] $MnSO_4$ recovered	Milligrams/[3] sq. meter	Equivalent[4] gallons/acre
D-2	60	Cylindrical	81.5	3.075	3.288×10^{-3}
D-4	60	Cylindrical	6.5	2.453×10^{-1}	2.622×10^{-4}
D-6	60	Cylindrical	5.0	1.887×10^{-1}	2.017×10^{-4}
D-8	60	Cylindrical	4.0	1.509×10^{-1}	1.614×10^{-4}
D-10	60	Cylindrical	2.5	9.434×10^{-2}	1.008×10^{-4}
D-12	60	Cylindrical	3.0	1.132×10^{-1}	1.210×10^{-4}
D-14	60	Cylindrical	2.5	9.434×10^{-2}	1.008×10^{-4}
D-16	700	Cylindrical	3.5	1.321×10^{-1}	1.412×10^{-4}
D-18	700	Cylindrical	2.5	9.434×10^{-2}	1.008×10^{-4}
D-20	700	Cylindrical	2.0	7.547×10^{-2}	8.068×10^{-5}
D-22	700	Cylindrical	2.0	7.547×10^{-2}	8.068×10^{-5}
D-24	700	Cylindrical	1.0	3.774×10^{-2}	4.034×10^{-5}
D-26	700	Cylindrical	1.5	5.660×10^{-2}	6.051×10^{-5}
D-66	120	Cylindrical	12.5	4.717×10^{-1}	5.042×10^{-4}
D-68	120	Cylindrical	3.5	1.321×10^{-1}	1.412×10^{-4}
D-70	120	Cylindrical	2.5	9.434×10^{-2}	1.008×10^{-4}
D-72	120	Cylindrical	3.0	1.132×10^{-1}	1.210×10^{-4}
D-74	120	Cylindrical	5.0	1.887×10^{-1}	2.017×10^{-4}
D-76	120	Cylindrical	7.5	2.830×10^{-1}	3.025×10^{-4}
D-78	120	Cylindrical	5.5	2.075×10^{-1}	2.219×10^{-4}
D-80	120	Cylindrical	7.5	2.830×10^{-1}	3.025×10^{-4}

1. See Figure 13 for location of drift samplers, downwind distance to nearest spray swath.
2. Micrograms of $MnSO_4$ recovered from the cylinder sampler sides (34.8 square inches) and cylinder top (area 6.25 square inches), or flat deposit on ground (area 20.29 square inches).
3. Micrograms of $MnSO_4$ expanded from the sampler surface to a square meter. Blanks represent less than 0.0001 milligrams per square meter.
4. Amount of tank mix recovered in gallons per acre based upon the ratio of 1 part $MnSO_4$ to 83.37 parts water.

Table 24.-Trial 10 drift data; manganese sulfate recovered from Mylar sheets covering cylindrical samplers positioned vertically, or from Mylar sheets positioned horizontally on the ground, Withlacoochee State Seed Orchard Project, 1980.

Sampler[1] number	Distance downwind (ft)	Sampler type	Micrograms of[2] $MnSO_4$ recovered	Milligrams/[3] sq. meter	Equivalent[4] gallons/acre
D-2	60	Horizontal	78.5	5.997	6.411×10^{-3}
D-4	60	Horizontal	12.5	9.549×10^{-1}	1.021×10^{-3}
D-6	60	Horizontal	3.0	2.292×10^{-1}	2.450×10^{-4}
D-8	60	Horizontal	1.0	7.639×10^{-2}	8.167×10^{-5}
D-10	60	Horizontal	2.0	1.528×10^{-1}	1.633×10^{-4}
D-12	60	Horizontal	1.0	7.639×10^{-2}	8.167×10^{-5}
D-14	60	Horizontal	1.0	7.639×10^{-2}	8.167×10^{-5}
D-16	700	Horizontal	1.0	7.639×10^{-2}	8.167×10^{-5}
D-18	700	Horizontal	2.0	1.528×10^{-1}	1.633×10^{-4}
D-20	700	Horizontal	2.0	1.528×10^{-1}	1.633×10^{-4}
D-22	700	Horizontal	2.0	1.528×10^{-1}	1.633×10^{-4}
D-24	700	Horizontal	2.0	1.528×10^{-2}	1.633×10^{-4}
D-26	700	Horizontal	1.5	1.146×10^{-1}	1.225×10^{-4}
D-66	120	Horizontal	25.5	1.948	2.082×10^{-3}
D-68	120	Horizontal	11.5	8.785×10^{-1}	9.392×10^{-4}
D-70	120	Horizontal	7.5	5.730×10^{-1}	6.125×10^{-4}
D-72	120	Horizontal	14.0	1.070	1.143×10^{-3}
D-74	120	Horizontal	22.5	1.719	1.837×10^{-3}
D-76	120	Horizontal	21.5	1.642	1.756×10^{-3}
D-78	120	Horizontal	29.0	2.215	2.368×10^{-3}
D-80	120	Horizontal	9.5	7.257×10^{-1}	7.758×10^{-4}

1. See Figure 13 for location of drift samplers, downwind distance from nearest spray swath.
2. Micrograms of $MnSO_4$ recovered from the cylinder sampler side (34.8 square inches) and cylinder top (area 6.25 square inches), or horizontal flat deposit on ground (area 20.29 square inches).
3. Micrograms of $MnSO_4$ expanded from the sampler surface to a square meter. Blanks represent less than 0.0001 milligrams per square meter.
4. Amount of tank mix recovered in gallons per acre based upon the ratio of 1 part $MnSO_4$ to 83.37 parts water.

Table 25.-Trial 7 drift data: manganese sulfate recovered from Mylar sheets covering cylindrical samplers positioned vertically, or from Mylar sheets positioned horizontally on the ground, Withlacoochee State Seed Orchard Project, 1980.

Sampler[1] number	Distance downwind (ft)	Sampler type	Micrograms of[2] $MnSO_4$ recovered	Milligrams/[3] sq. meter	Equivalent[4] gallons/acre
D-2	60	Cylindrical	38.4	1.449	1.549×10^{-3}
D-4	60	Cylindrical	20.1	7.585×10^{-1}	8.108×10^{-4}
D-6	60	Cylindrical	1.3	4.906×10^{-2}	5.244×10^{-5}
D-8	60	Cylindrical	1.4	5.283×10^{-2}	5.648×10^{-5}
D-10	60	Cylindrical	1.3	4.906×10^{-2}	5.244×10^{-5}
D-12	60	Cylindrical	1.5	5.660×10^{-2}	6.051×10^{-5}
D-14	60	Cylindrical	1.6	6.038×10^{-2}	6.454×10^{-5}
D-16	700	Cylindrical	1.2	4.528×10^{-2}	4.841×10^{-5}
D-18	700	Cylindrical	1.7	6.415×10^{-2}	6.858×10^{-5}
D-20	700	Cylindrical	1.2	4.528×10^{-2}	4.841×10^{-5}
D-22	700	Cylindrical	1.7	6.415×10^{-2}	6.858×10^{-5}
D-24	700	Cylindrical	1.4	5.283×10^{-2}	5.648×10^{-5}
D-26	700	Cylindrical	1.2	4.528×10^{-2}	4.841×10^{-5}
D-28	700	Cylindrical	1.7	6.415×10^{-2}	6.858×10^{-5}
D-30	700	Cylindrical	0.5	1.887×10^{-2}	2.017×10^{-5}
D-32	700	Cylindrical	1.6	6.038×10^{-2}	6.454×10^{-5}
D-34	700	Cylindrical	2.0	7.547×10^{-2}	8.068×10^{-5}
D-36	700	Cylindrical	1.9	7.170×10^{-2}	7.665×10^{-5}

1. *See Figure 13 for location of drift samplers, downwind distance to nearest spray swath.*
2. *Micrograms of $MnSO_4$* recovered from the cylinder sampler sides (34.8 square inches) and cylinder top (area 6.25 square inches), or horizontal flat deposit on ground (area 20.29 square inches).
3. Micrograms of $MnSO_4$ expanded from the sampler surface to a square meter. Blanks represent less than 0.0001 milligrams per square meter.
4. Amount of tank mix recovered in gallons per acre based upon the ratio of 1 part $MnSO_4$ to 83.37 parts water.

Table 26.-Trial 7 drift data; manganese sulfate recovered from Mylar sheets covering cylindrical samplers positioned vertically, or from Mylar sheets positioned horizontally on the ground, Withlacoochee State Seed Orchard Project, 1980.

Sampler[1] number	Distance downwind (ft)	Sampler type	Micrograms of[2] $MnSO_4$ recovered	Milligrams/[3] sq. meter	Equivalent[4] gallons/acre
D-2	60	Horizontal	152.4	1.164×10	1.245×10^{-2}
D-4	60	Horizontal	56.0	4.278	4.573×10^{-3}
D-6	60	Horizontal	1.8	1.375×10^{-1}	1.470×10^{-4}
D-8	60	Horizontal	1.4	1.070×10^{-1}	1.143×10^{-4}
D-10	60	Horizontal	1.1	8.403×10^{-2}	8.983×10^{-5}
D-12	60	Horizontal	1.0	7.639×10^{-2}	8.167×10^{-5}
D-14	60	Horizontal	0.5	3.820×10^{-2}	4.083×10^{-5}
D-16	700	Horizontal	0.5	3.820×10^{-2}	4.083×10^{-5}
D-18	700	Horizontal	0.4	3.056×10^{-2}	3.267×10^{-5}
D-20	700	Horizontal	0.4	3.056×10^{-2}	3.267×10^{-5}
D-22	700	Horizontal	0	--	--
D-24	700	Horizontal	1.0	7.639×10^{-2}	8.167×10^{-5}
D-26	700	Horizontal	0.7	5.348×10^{-2}	5.717×10^{-5}
D-28	700	Horizontal	0.7	5.348×10^{-2}	5.717×10^{-5}
D-30	700	Horizontal	0.3	2.292×10^{-2}	2.450×10^{-5}
D-32	700	Horizontal	0.7	5.348×10^{-2}	5.717×10^{-5}
D-34	700	Horizontal	0.7	5.348×10^{-2}	5.717×10^{-5}
D-36	700	Horizontal	0.8	6.112×10^{-2}	6.533×10^{-5}

1. See Figure 13 for location of drift samplers, downwind distance to nearest spray swath.
2. Micrograms of $MnSO_4$ recovered from the cylinder sampler sides (34.8 square inches) and cylinder top (area 6.25 square inches), or horizontal flat deposit on ground (area 20.29 square inches).
3. Micrograms of $MnSO_4$ expanded from the sampler surface to a square meter. Blanks represent less than 0.0001 milligrams per square meter.
4. Amount of tank mix recovered in gallons per acre based upon the ratio of 1 part $MnSO_4$ to 83.37 parts water.

Table 27.–Trial drift data; manganese sulfate recovered from Mylar sheets covering cylindrical samplers positioned vertically, or from Mylar sheets positioned horizontally on the ground, Withlacoochee State Seed Orchard Project, 1980.

Sampler[1] number	Distance downwind (ft)	Sampler type	Micrograms of[2] $MnSO_4$ recovered	Milligrams/[3] sq. meter	Equivalent[4] gallons/acre
D-53	60	Cylindrical control	0	--	--
D-60	150	Cylindrical	0	--	--
D-70	150	Cylindrical	0.8	3.019×10^{-2}	3.227×10^{-5}
D-42	150	Cylindrical	0.3	1.132×10^{-2}	1.210×10^{-5}
D-44	150	Cylindrical	1.0	3.774×10^{-2}	4.034×10^{-5}
D-46	150	Cylindrical	0.3	1.132×10^{-2}	1.210×10^{-5}
D-48	150	Cylindrical	0.8	3.019×10^{-2}	3.227×10^{-5}
D-50	150	Cylindrical	0.8	3.019×10^{-2}	3.227×10^{-5}
D-52	150	Cylindrical	24.0	9.057×10^{-1}	9.682×10^{-4}
D-54	150	Cylindrical	40.5	1.528	1.634×10^{-3}
D-56	150	Cylindrical	10.8	4.075×10^{-1}	4.357×10^{-4}
D-58	150	Cylindrical	6.8	2.566×10^{-1}	2.743×10^{-4}
D-60	150	Cylindrical	11.8	4.453×10^{-1}	4.760×10^{-4}
D-62	150	Cylindrical	8.0	3.019×10^{-1}	3.227×10^{-4}
D-64	150	Cylindrical	3.5	1.321×10^{-1}	1.412×10^{-4}
D-66	150	Cylindrical	8.5	3.208×10^{-1}	3.429×10^{-4}
D-68	150	Cylindrical	53.3	2.011	2.150×10^{-3}
D-70	150	Cylindrical	21.8	8.226×10^{-1}	8.794×10^{-4}
D-72	150	Cylindrical	3.5	1.321×10^{-1}	1.412×10^{-4}
D-74	150	Cylindrical	16.3	6.151×10^{-1}	6.575×10^{-4}
D-76	150	Cylindrical	6.0	2.264×10^{-1}	2.420×10^{-4}
D-78	150	Cylindrical	10.5	3.962×10^{-1}	4.236×10^{-4}
D-80	150	Cylindrical	13.0	4.906×10^{-1}	5.244×10^{-4}
D-82	150	Cylindrical	18.3	6.906×10^{-1}	7.382×10^{-4}

1. See Figure 13 for location of drift samplers, downwind distance to nearest spray swath.
2. Micrograms of $MnSO_4$ recovered from the cylinder sampler sides (34.8 square inches) and cylinder top (area 6.25 square inches), or horizontal flat deposit on ground (area 20.29 square inches).
3. Micrograms of $MnSO_4$ expanded from the sampler surface to a square meter. Blanks represent less than 0.0001 milligrams per square meter.
4. Amount of tank mix recovered in gallons per acre based upon the ratio of 1 part $MnSO_4$ to 83.37 parts water.

Table 28. - Trial 5 drift data; manganese sulfate recovered from Mylar sheets covering cylindrical samplers positioned vertically, or from Mylar sheets positioned horizontally on the ground, Withlacoochee State Seed Orchard Project, 1980.

Sampler[1] number	Distance downwind (ft)	Sampler type	Micrograms of[2] $MnSO_4$ recovered	Milligrams/[3] sq. meter	Equivalent[4] gallons/acre
D-53	60	Horizontal control	0.5	3.820×10^{-2}	4.083×10^{-5}
D-60	150	Horizontal	0	--	--
D-70	150	Horizontal	0.5	3.820×10^{-2}	4.083×10^{-5}
D-42	150	Horizontal	11.3	8.633×10^{-1}	9.228×10^{-4}
D-44	150	Horizontal	2.0	1.528×10^{-1}	1.633×10^{-4}
D-46	150	Horizontal	2.5	1.910×10^{-1}	2.042×10^{-4}
D-48	150	Horizontal	2.8	2.139×10^{-1}	2.287×10^{-4}
D-50	150	Horizontal	1.5	1.146×10^{-1}	1.225×10^{-4}
D-52	150	Horizontal	62.8	4.798	5.129×10^{-3}
D-54	150	Horizontal	62.5	4.775	5.104×10^{-3}
D-56	150	Horizontal	34.5	2.636	2.817×10^{-3}
D-58	150	Horizontal	26.5	2.024	2.164×10^{-3}
D-60	150	Horizontal	37.8	2.888	3.087×10^{-3}
D-62	150	Horizontal	41.8	3.193	3.414×10^{-3}
D-64	150	Horizontal	8.8	6.723×10^{-1}	7.187×10^{-4}
D-66	150	Horizontal	20.8	1.589	1.699×10^{-3}
D-68	150	Horizontal	130.3	9.954	1.064×10^{-2}
D-70	150	Horizontal	23.3	1.780	1.903×10^{-3}
D-72	150	Horizontal	7.5	5.730×10^{-1}	6.125×10^{-4}
D-74	150	Horizontal	58.8	4.492	4.802×10^{-3}
D-76	150	Horizontal	18.3	1.398	1.494×10^{-3}
D-78	150	Horizontal	24.8	1.895	2.025×10^{-3}
D-80	150	Horizontal	16.8	1.283	1.372×10^{-3}
D-82	150	Horizontal	10.0	7.639×10^{-1}	8.167×10^{-4}

1. See Figure 13 for location of drift samplers, downwind distance to nearest spray swath.
2. Micrograms of $MnSO_4$ recovered from the cylinder sampler sides (34.8 square inches) and cylinder top (area 6.25 square inches), or horizontal flat deposit on ground (area 20.29 square inches).
3. Micrograms of $MnSO_4$ expanded from the sampler surface to a square meter. Blanks represent less than 0.0001 milligrams per square meter.
4. Amount of tank mix recovered in gallons per acre based upon the ratio of 1 part $MnSO_4$ to 83.37 parts water.

Special drift study: Six trials were conducted the afternoon of February 20, 1980, over an open area at the orchard to take a preliminary look at how far a water base spray with and without Nalco Trol might travel downwind. Kromekote card samplers were placed on the ground at positions shown in Figure 14. Results of the study are presented in Tables 29 and 30. No measurable drops were observed on samplers beyond 133 meters downwind. The wind (Fig. 24) during these trials ranged from 6 to 16 mph under unstable, turbulent conditions. Conventional wisdom suggests that winds would favor drifting; however, the unstable afternoo air mixes, deposits, diffuses, and dilutes the cloud. Early morning conditions, typically low winds, and stable air are more conducive to drift than conditions existing under unstable conditions. These data were not analyzed for significance between the Nalco Trol and non-Nalco Trol trials, as the limited trials and data did not support analyses.

Meteorological Conditions

Trial	Wind Speed	Wind Direction	Dry Bulb	Wet Bulb
1	6 mph	SSW		
2	7 mph	W		
3	8-13 mph	W		
4	1-4 mph	W	78°F	68°F
5	16 mph	W	79°F	64°F
6	8 mph	W	76°F	63°F

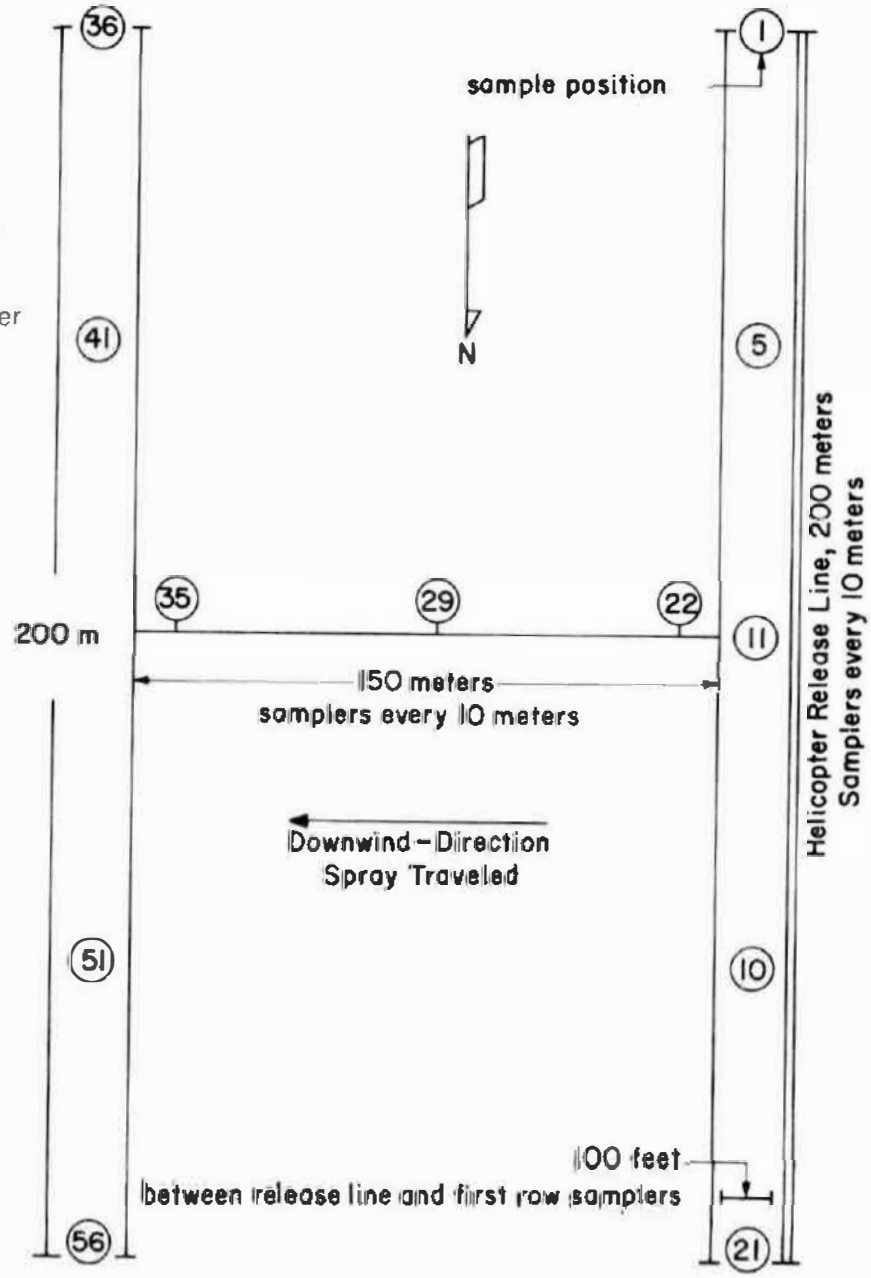


Figure 14. – Diagram of sampling array for special drift study conducted in conjunction with Withlacoochee State Seed Orchard Project, February 20, 1980. Hughes 500C helicopter applied dyed water at 5 gallons per acre, 25 feet above ground, 25 mph, and normal to wind direction along a 200-meter line. Samplers were placed every 10 meters and numbered consecutively.

Table 29.–Deposit data for Trials 1-3 without Nalco Trol and Trials 4-6 with Nalco Trol. Ounces per acre observed on Kromekote cards by position, Withlacoochee Spray Drift Trials, Florida, February 1980.

Sample no.	Distance Downwind (meters)	Without Nalco Trol			With Nalco Trol		
		1	2	3	4	5	6
		OZ/ACRE			OZ/ACRE		
1	33	98.1	174.1	13.6	38.7	84.9	60.7
2	33	58.0	62.3	34.6	34.6	85.3	342.4
3	33	73.1	356.3	110.0	31.5	52.5	74.8
4	33	123.2	156.0	23.9	46.6	11.5	44.6
5	33	98.4	215.1	239.3	11.5	218.7	0
6	33	142.8	80.3	385.2	0.1	192.8	11.5
7	33	121.3	244.6	76.4	0.1	48.1	23.6
8	33	84.5	151.0	118.6		120.7	0
9	33	74.8	337.0	97.2		97.8	78.6
10	33	127.4	100.7	40.4			
11	33	73.4	205.2	156.2	23.0		
12	33	127.7	255.7	129.9			
13	33	62.1	131.5	44.8			
14	33	68.2	115.4		91.1		
15	33	64.9	118.2				
16	33	116.0	50.6				
17	33	46.1	21.9				
18	33	197.9				23.6	
19	33	154.4					
20	33	104.6		6.4			
21	33	4.3		41.4			
22	43	205.3	154.5	133.7	11.7	29.8	25.6
23	53	56.0	77.4	97.6	15.1	45.0	97.0
24	63	18.4	57.4	33.4	37.2	68.4	58.9
25	73		11.5	10.4	5.1	8.3	34.4
26	83		1.5	2.1	3.5		4.4
27	93		4.9	1.6	7.5		27.3
28	103		0.6		11.1		4.8
29	113		2.0		3.1		35.9
30	123		0.6		1.3		1.3
31	133		0.5		0.7		0.2

Blanks = 0; no drops observed on Kromekote cards beyond 133 meters. Hughes 500C helicopter applied dyed water at 5 gallons per acre, 25 feet above ground, 25 mph, and normal to wind direction along a 200-meter line.

Table 30.-Deposit data for Trials 1-3 without Nalco Trol and Trials 4-6 with Nalco Trol. Drops per centimeter square observed on Kromekote cards by position, Withlacoochee Spray Drift Trials, Florida. February 1980.

Sample no.	Distance Downwind (meters)	Without Nalco Trol			With Nalco Trol		
		1	2	3	4	5	6
		Drops/cm²			Drops/cm²		
1	33	9.09	18.05	0.13	0.50	16.79	1.77
2	33	6.82	8.33	0.76	0.50	17.80	23.98
3	33	6.44	18.93	14.14	0.50	2.15	9.09
4	33	13.50	21.20	6.18	0.50	0.13	11.11
5	33	11.61	17.92	9.21	0.13	2.90	0.38
6	33	16.53	17.17	14.89	0.13	17.17	
7	33	13.13	15.15	12.24	0.13	5.68	0.13
8	33	13.38	12.50	13.75		6.31	0.13
9	33	12.62	16.03	17.29		3.28	0.13
10	33	18.05	14.77	2.65			
11	33	14.39	11.11	14.39	0.25		
12	33	7.45	15.02	4.92			
13	33	10.48	14.26	0.63			
14	33	15.40	30.67		1.39		
15	33	9.34	21.96		0.25		
16	33	15.52	3.53				
17	33	16.53	.88				
18	33	14.39				0.13	
19	33	15.02					
20	33	8.71		0.50			
21	33	1.64		7.32			
22	43	14.39	8.33	16.28	15.40	4.80	0.38
23	53	9.21	4.42	12.37	8.96	10.73	10.98
24	63	4.04	4.67	5.05	3.79	5.30	6.18
25	73		2.15	1.39	1.39	1.64	4.54
26	83		0.50		2.65		0.25
27	93		1.01	0.63	1.64		1.77
28	103		0.25		2.02		1.01
29	113		0.50		1.64		2.27
30	123		0.50		1.14		0.76
31	133		0.13		0.76	0.50	

Blanks = 0, no drops observed on Kromekote cards beyond 133 meters. Hughes 500C helicopter applied dyed water at 5 gallons per acre, 25 feet above ground, 25 mph, and normal to wind direction along a 200-meter line.

CONCLUSIONS

Results of these trials clearly support the use of aircraft to apply pesticides to southern pine seed orchards. Helicopter performance at 25 mph forward speed in terms of spray coverage in the trees was superior to that of the Stearman. Both models of ground sprayers achieved spray coverage equal to or greater than that of the helicopter.

Ground sprayers, such as the mist-type designed for orchard use, will provide adequate spray coverage of southern pines ranging in heights below 50 feet. It is essential, however, that the equipment be in good condition, that the proper nozzles and positioning be used, that the equipment be calibrated accurately, and that the operators be proficient in the use of the equipment.

Results and experience gained from this demonstration provided the basis for an aerial application strategy or spray prescription for treating seed orchards.

The utility of the FS CBG model as a tool for planning and evaluating seed orchard aerial application was demonstrated.

Minimal but detectable spray drift can be expected to occur 133 meters downwind, depending upon wind speed, wind direction, and other atmospheric conditions. Additionally, off-target deposits can be expected at the ends of treatment blocks where the applicator makes his turns.

As part of the technology transfer process we presented results of the Withlacoochee test to the 1980 ASAE/NAAA joint technical session, sponsored by the National Agricultural Aviation Association, Las Vegas, Nevada (Barry et al. 1980). A paper was published also in a journal (Barry et al. 1981) on the Withlacoochee data. We plan to publish findings oriented to the orchard manager in the Journal of Southern Forestry. The SA sent a technology update on aerial application of insecticides to southern pine seed orchards to federal, state, and private seed orchard managers which covered information learned at Withlacoochee. This report will be distributed to FS pesticide specialists and their cooperators.

RECOMMENDATIONS

1. Conduct tests to obtain data on spray coverage and deposition resulting from aircraft spraying on 60-foot swaths. Increasing swaths from 30 feet to 60 feet could reduce application costs up to 40 percent.

2. Determine the bio-mass and surface area, represented by foliage of various orchard-grown southern pines. This information is important in calculating the application rate, droplet size, and method of application to insure the proper amount of active ingredient is applied for surface coverage. There is an optimum level of active ingredient balanced between considerations for safety, economics, and efficacy. It is recommended that additional field testing be conducted to establish optimum application volumes for different species and sizes of southern pines. Specifically data are needed on efficacy relative to surface coverage and toxic dosage.

Evaluate the utility of ULV and LV spray application to seed orchards.

Conduct seed orchard trials to compare drift from both ground and aerial sprayers. Data on spray drift is needed for various atmospheric conditions, which may be encountered during ground and aerial application.

Aerial application recommendations (Table 31) are based upn results of the Withlacoochee test and results of a two-year pilot project in the Southeastern Area involving application of Guthion' and Pydrin', discussions with entomologists and seed orchard managers, and personal observations. These recommendations will be updated as more information becomes available.

Table 31. Recommended parameters for aerial application of 5 gallon per acre to pine seed orchards.

Parameter	Helicopter	Fixed-Wing
Droplet size (VMD)-Micrometer	300-350	300-350
Speed (mph)	50	100
Swath (ft)	60	60
Release height above trees (ft)	5	5
Approximate number and kind of nozzles	(67 ea.) D-5-45[1]	(55 ea.) D-6-46[1]
Adjuvant	Nalco Trol 2-3 oz/100 gal. of tank mix	Nalco Trol 2-3 oz/ 100 gal. of tank mix
Boom Pressure (psi)	40	40
Nozzle orientation	Straight back[2]	Down and back 30°[3]

1. Approximate number of nozzles-aircraft must be calibrated in the field. Nozzles manufactured by Spraying Systems Co.
2. To affect maximum shear action and atomization of nozzle caused by downwash of rotor.
3. With airplane in flight attitude.

REFERENCES

Metcalf, R. L. (editor). 1958. Advances in Pest Control Research, Vol. II. Interscience Publishers, Inc. New York, New York.

Rafferty, J. E., R. D. Dumbauld, H. W. Flake, J. W. Barry, and J. Wong. 1981. Comparison of modeled and measured deposition for the Withlacoochee spray trials. Report No. 81-3. Produced under contract 53-9158-9-6260 by H. E. Cramer Co., Salt Lake City, Utah. USDA Forest Service, Forest Pest Management, Methods Application Group, Davis, California 95616.

Barry, John W., Robert B. Ekblad, and Larry Barber. 1980. Aerial application to coniferous seed orchards. Presented to the 1980 ASAE/NAAA jointly sponsored technical session on agricultural aviation research at the National Agricultural Aviation Association annual meeting, Las Vegas, Nevada.

Barry, J. W., J. Wong, P. Kenney, L. Barber, H. Flake, and R. Ekblad. 1981. Deposition of pesticide drops on pine foliage from aerial application. Zeitschrift fur angewandte Entomologie, Sonderdruck aus Bd. 92 (1981), H. 3, S. 224-232.

Rafferty, J. E. and R. K. Dumbauld. 1980. Selection of spray operations criteria for the Withlacoochee State Orchard Project. Report No. 80-8 under Contract No. 53-01S8-9-6260, Methods Application Group, USDA Forest Service, Davis, California.

Young, Robert W., Raymond C. Luebbe, and John W. Barry. 1977. ASCAS-data management system for aerial deposits. Report No. 77-2. USDA Forest Service, Methods Application Group, Forest Insect and Disease Management, Davis, California.

Steel, Robert G. D. and J. H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Company, Inc. 481 pp.

Anonymous. 1966. Helicopter techniques for aerial application. Bell Helicopter Co.

Goldstein, A. 1965. Biostatics. New York: The MacMillan Co.

Ware, G. W., E. J. Apple, W. P. Cahill, P. D. Gerhardt, and K. R. Frost. 1969. Pesticide Drift. II. Mist-blower vs. aerial application of sprays. Journal of Economical Entomology, Vol. 62:4, pp 844-846.

APPENDICES

Appendix A

Table A-1. Notes on application. Withlacoochee State Seed Orchard, February 1980.

Trial 1 w/Nalco Trol - Stearman Feb. 13, 1980
Release height: 20' Gallons sprayed: 80

Swath	*Row location*
1	Between 7 and 8
2	Over 7
3	Between 5 and 6
4	Between 4 and 5
5	Between 3 and 4, but closer to row 4
6	Between 2 and 3
7	Between 1 and 2

Trial 2 w/Nalco Trol - Stearman Feb. 15, 1980
Release height: 20' Gallons sprayed: 80

Swath	*Row location*
1	Between 10 and 11
2	Between 9 and 10
3	Between 8 and 9
4	Between 7 and 8
5	Between 6 and 7
6	Between 5 and 6
7	Between 4 and 5

Trial 3 w/Nalco Trol - Stearman Feb. 15, 1980
Release height: 20' Gallons sprayed: 77

Swath	*Row location*
1	Over 10
2	Over 9
3	Over 8
4	Over 7
5	Over 6
6	Over 5
7	Over 4
8	Over 3

Trial 4 w/Nalco Trol - FMC Sprayer Feb. 15, 1980
G-10 row shifted west

NOTE: All trials started south to north. Flagging began with Trial 6.

Trial 5

w/Nalco Trol and manganese - Stearman Feb. 16, 1980

Release height: 5' Gallons sprayed: 83

Swath	*Row location*
1	Between 4 and 5
2	Between 4 and 5
3	Between 5 and 6
4	Between 6 and 7
5	Between 7 and 8
6	Between 8 and 9
7	Between 9 and 10
8	Between 10 and 11
9	Between 11 and 12

Trial 6

w/Nalco Trol and manganese - Stearman Feb. 16, 1980

Release height: 5' Gallons sprayed: 65

Swath	*Row location*
1	Between 2 and 3
2	Between 3 and 4
3	Between 4 and 5
4	Between 5 and 6
5	Between 6 and 7, but plane wandered to east
6	Between 7 and 8
7	Between 8 and 9
8	Between 9 and 10
9	Between 10 and 11

Trial 7

w/Nalco Trol and manganese - Stearman Feb. 18, 1980

Release height: 5' Gallons sprayed: 15

Swath	*Row location*
1	Between 9 and 10
2	Between 8 and 9
3	Between 7 and 8
4	Between 6 and 7
5	Between 5 and 6
6	Between 4 and 5
7	Between 3 and 4
8	Between 2 and 3
9	Between 1 and 2

NOTE: Only 15 gallons sprayed due to burned out bearing in pump.

Trial 8

w/Nalco Trol - Stearman Feb. 19, 1980

Release height: 5' Gallons sprayed: 100

Swath	*Row location*
1	Over 2
2	Over 3
3	Over 4
4	Over 5
5	Over 6
6	Over 7
7	Over 8
8	Over 9, but ran out of spray on this row

Trial 9
w/Nalco Trol - FMC sprayer Feb. 19, 1980
5 oz. Nalco Trol/7.5 pts. dye/250 gal. mix
Trial 10
w/Nalco Trol and manganese - Hughes 500C Feb. 19, 1980
Release height: 5'

Swath	*Row location*
1	Over 10
2	Over 10
3	Over 9
4	Over 8
5	Over 7
6	Over 6
7	Over 5
8	Over 4
9	Over 3
10	Over 2

NOTE: Only 92 gallons sprayed.
Trial 11
w/Nalco Trol - Hughes 500C Feb. 20, 1980
Release height: 5'

Swath	*Row location*
1	Between 2 and 3
2	Between 3 and 4, but closer to 3
3	Between 4 and 5
4	Between 5 and 6
5	Between 6 and 7
6	Between 7 and 8
7	Between 8 and 9
8	Between 9 and 10
9	Between 10 and 11

NOTE: Left outermost nozzle spraying to side.
Trial 12
w/Nalco Trol - Hughes 500C Feb. 20, 1980
Release height: 5'

Swath	*Row location*
1	Between 2 and 3
2	Between 3 and 4
3	Between 4 and 5
4	Between 5 and 6
5	Between 6 and 7
6	Between 7 and 8
7	Between 8 and 9
8	Between 9 and 10
9	Between 10 and 11

Trial 13
w/Nalco Trol - Hughes 500C Feb. 20, 1980
Release height: 5'

Swath	*Row location*
1	Between 2 and 3
2	Between 3 and 4
3	Between 4 and 5
5	Between 6 and 7
6	Between 7 and 8
7	Between 8 and 9
8	Between 9 and 10
9	Between 10 and 11

Trial 14
w/o Nalco Trol - Hughes 500C Feb. 21, 1980
Release height: 5'

Swath	*Row location*
1	over 10
2	Over 9
3	Over 8
4	Over 7
5	Over 6
6	Over 5
7	Over 4
8	over 3
9	Over 2

Trial 15 w/Nalco Trol - FMC Sprayer Feb. 21, 1980
Trial 16 w/Nalco Trol - State Orchard Sprayer Feb. 21, 1980
Trial 17 w/Nalco Trol - State Orchard Sprayer Feb. 21, 1980
Trial 18 w/Nalco Trol - State Orchard Sprayer Feb. 22, 1980

Appendix B Plots of Canopy Penetration

Figures B-1 through B-11, which follow, are plots of spray drop penetration of the canopy. The spray collected below the spray aircraft, but above the orchard canopy, is assumed to be the spray distributions characteristic of that application. The spray droplets which are recovered on the forest or orchard floor represent what remains or what penetrates the canopy avoiding evaporation or scavenging by the foliage and eventually deposits on the floor. The plots by trial represent canopy penetration by drop size category. The 16 drop size categories represent drop sizes as follows:

Size Category	*Upper Drop Size (μm)*
1	109.7
2	121.2
3	146.0
4	202.1
5	231.8
6	281.3
7	359.9
8	438.6
9	615.7
10	709.7
11	866.5
12	1115.6
13	1408.2
14	1573.2
15	1660.7
16	2210.7

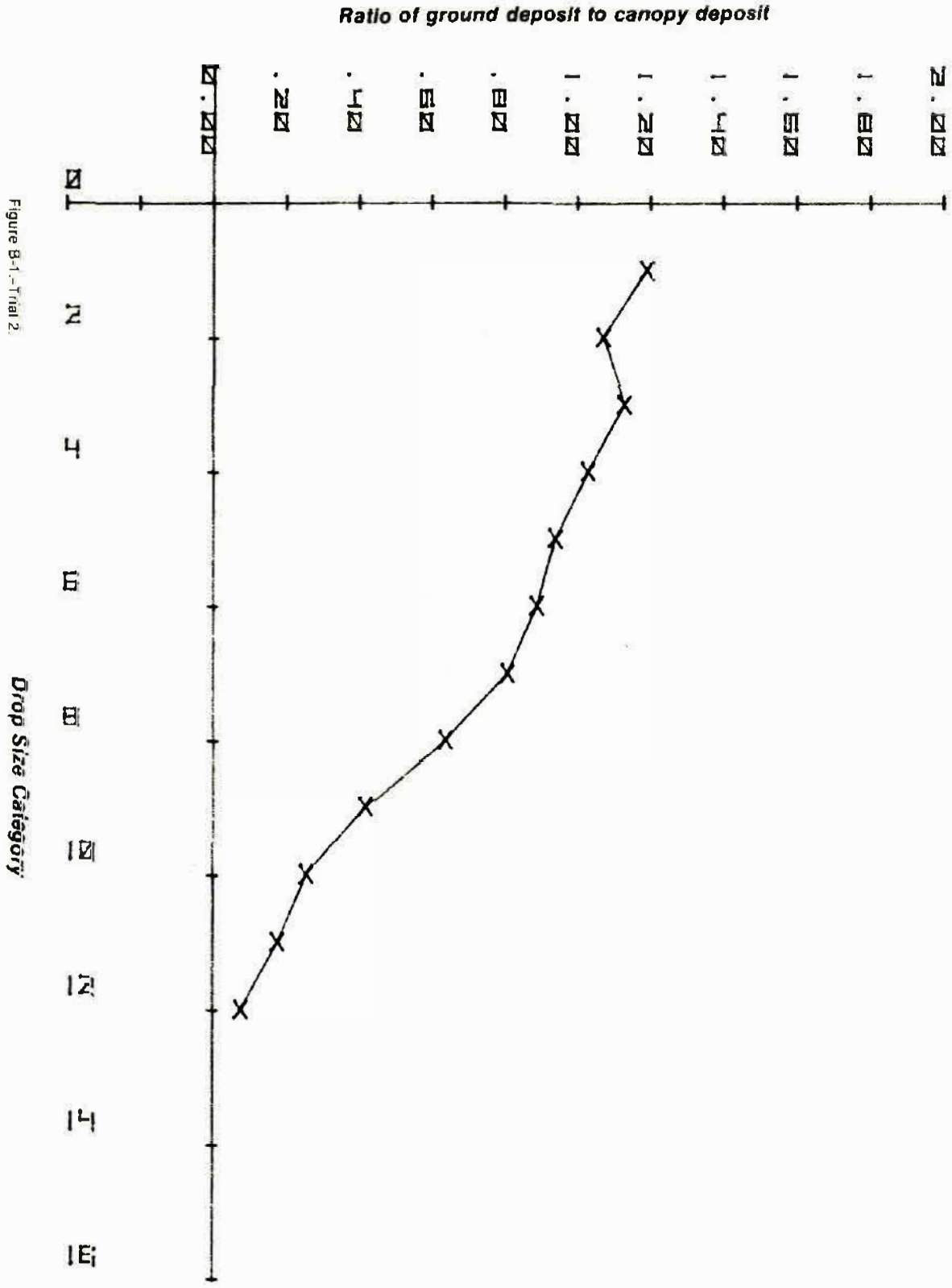


Figure B-1.--Trial 2.

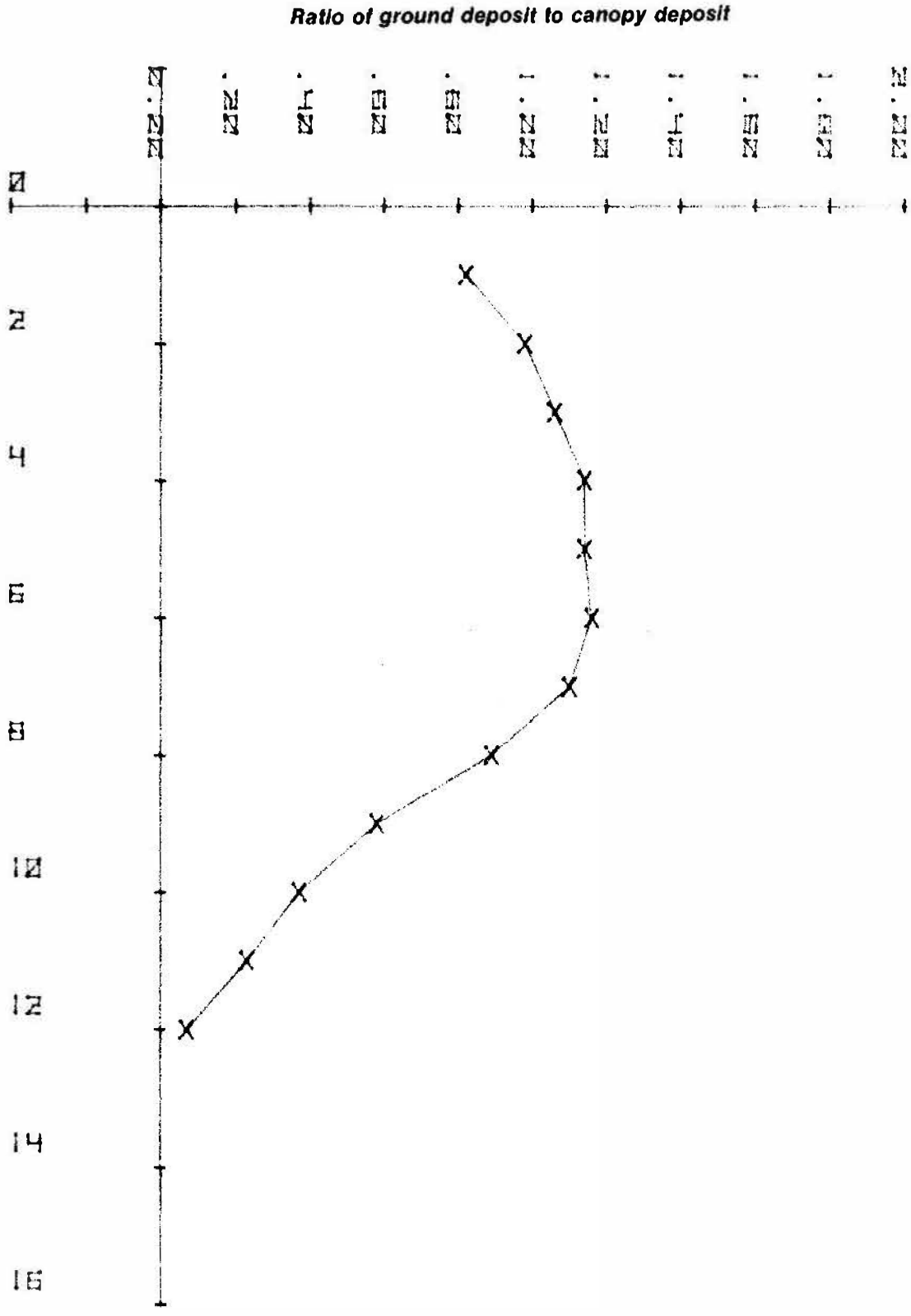


Figure B-2.-Trial 3.

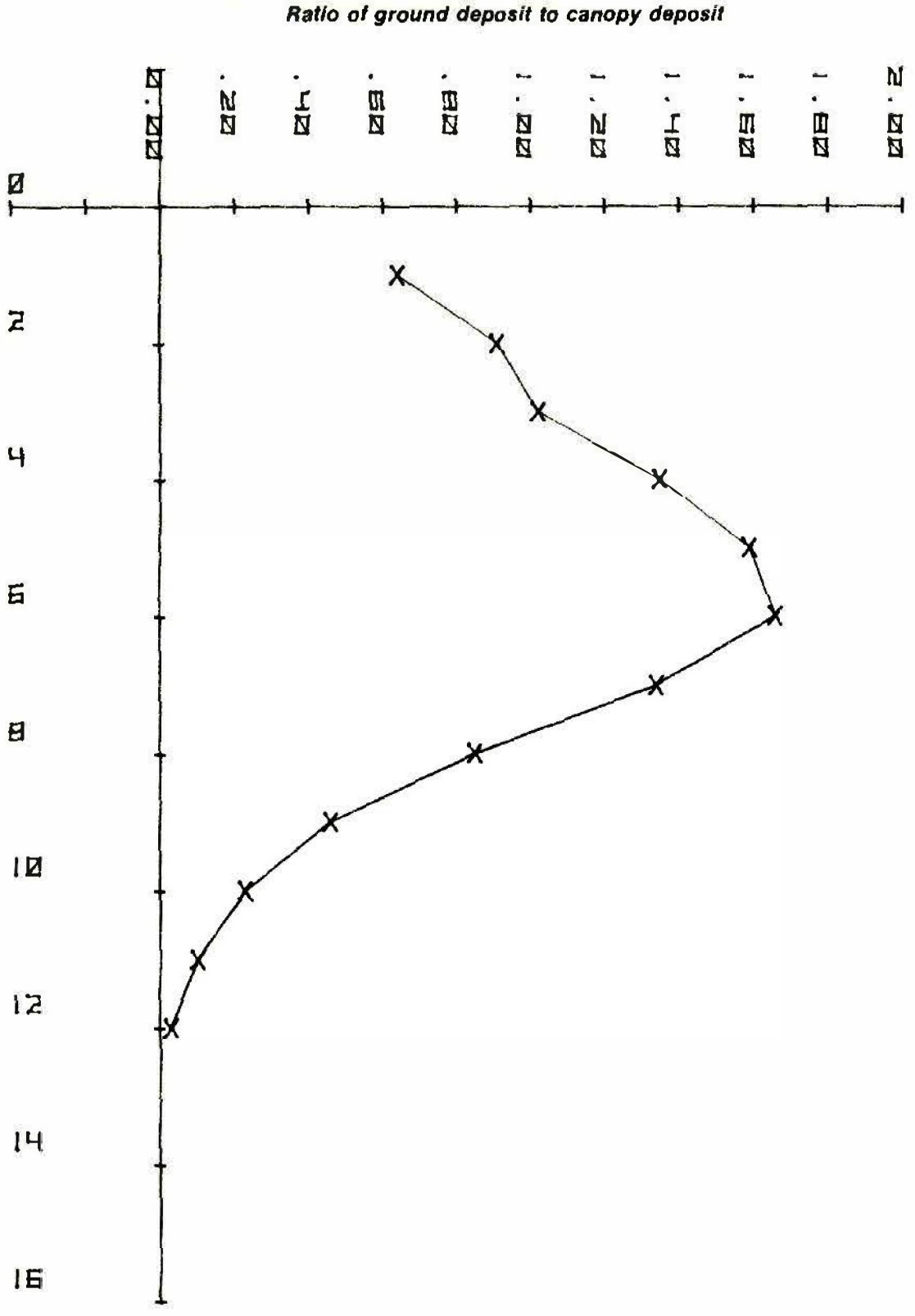


Figure B-3.–Trial 5.

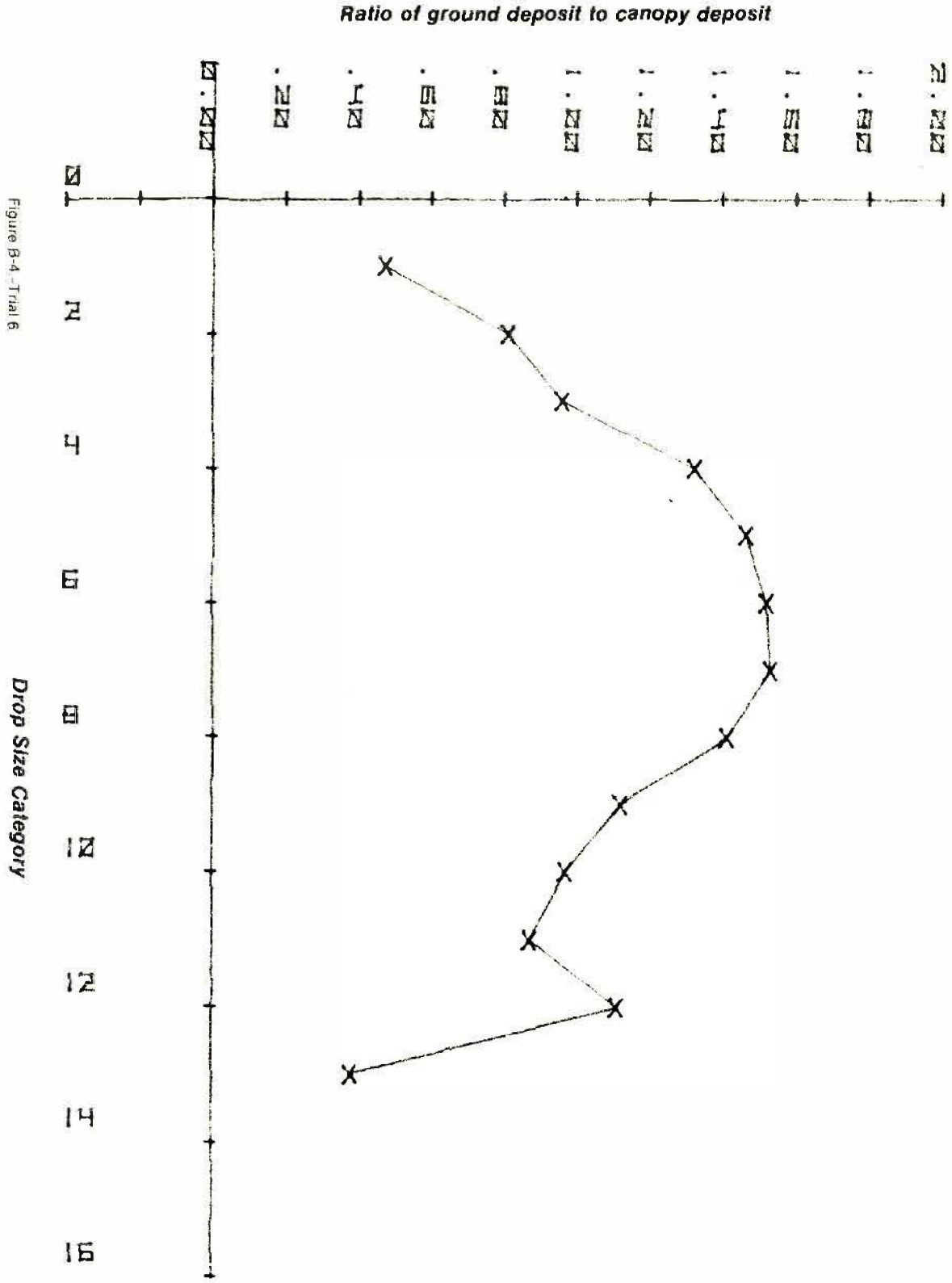


Figure B-4 -Trial 6

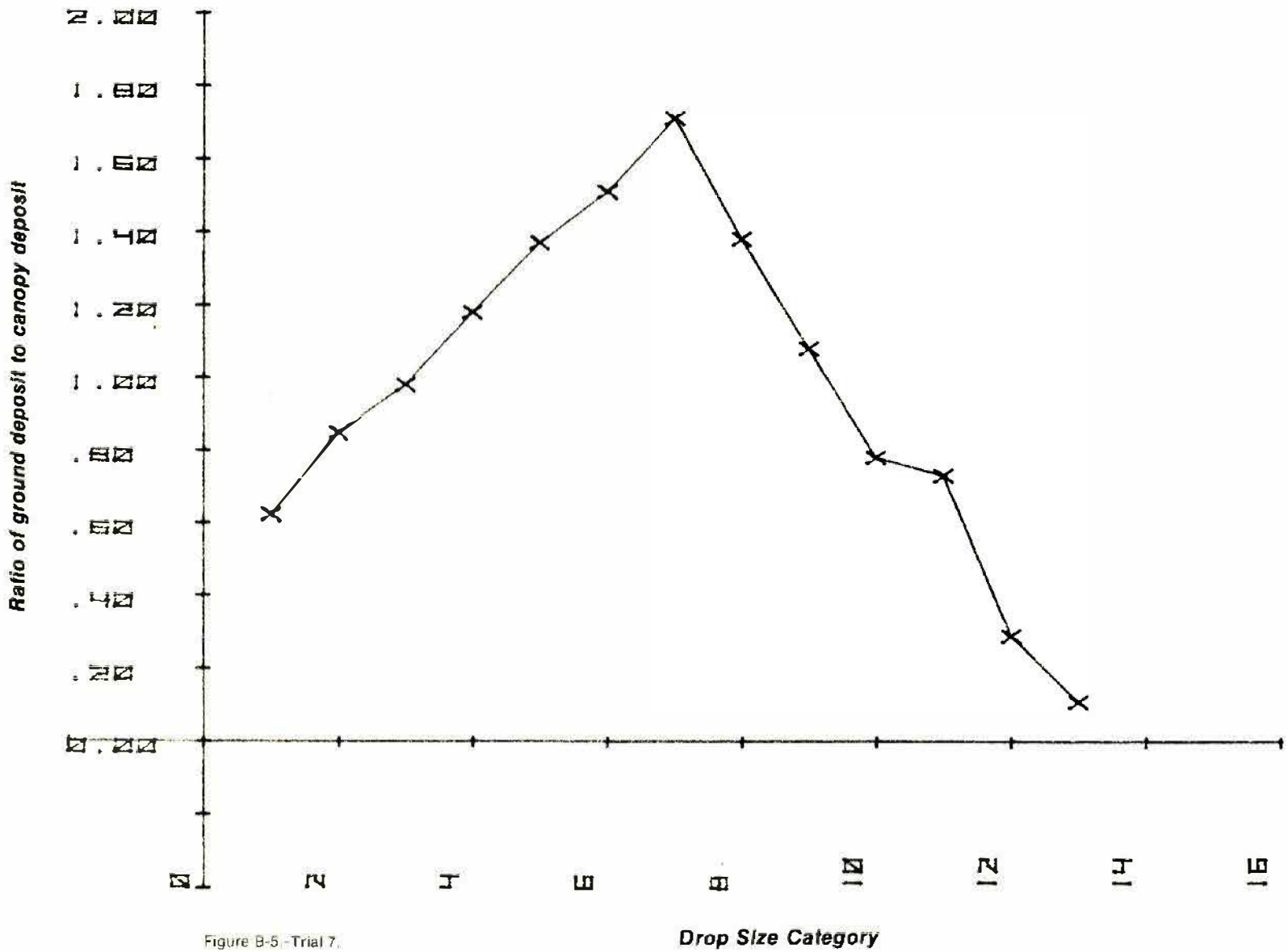


Figure B-5 -Trial 7.

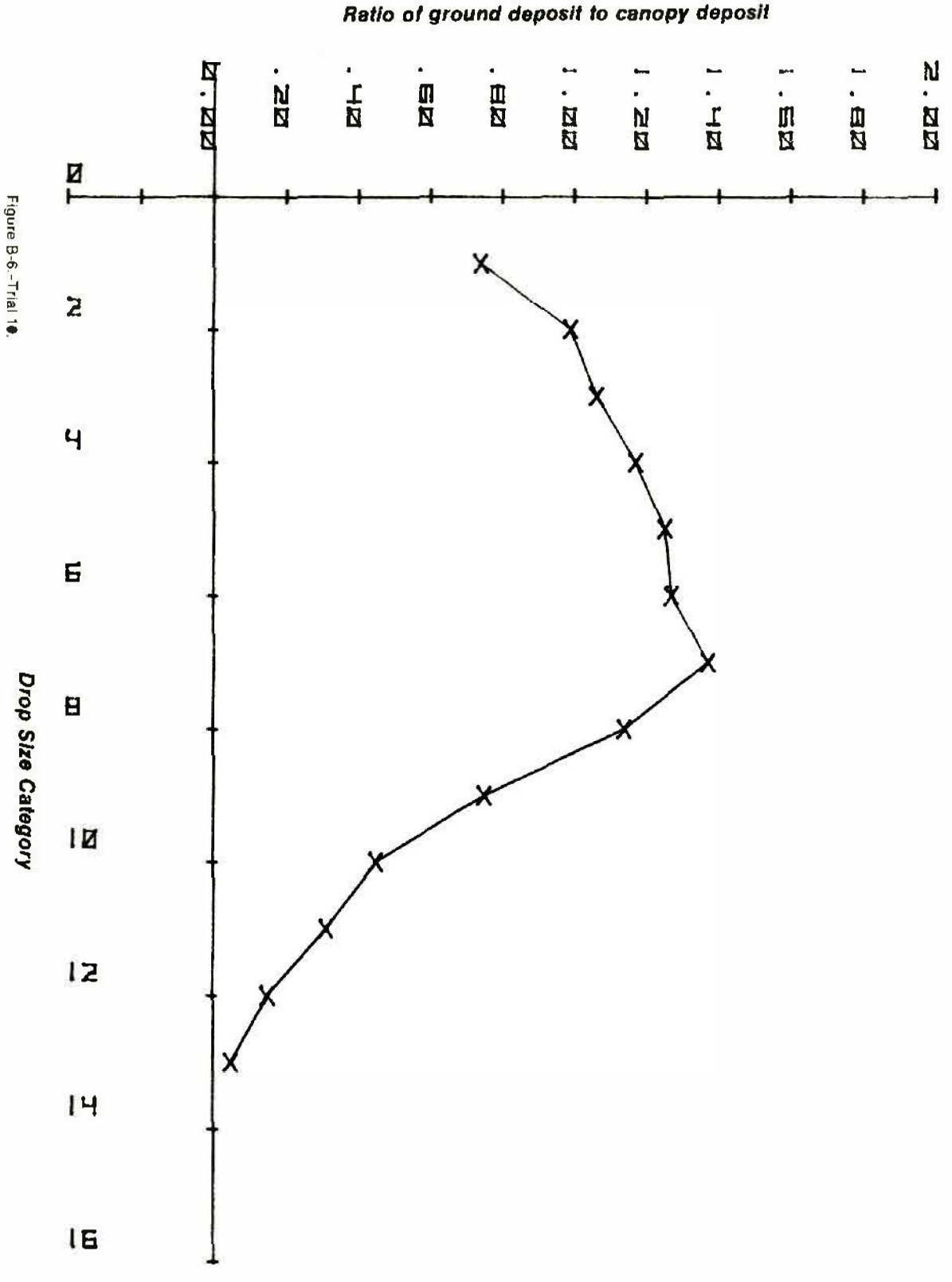


Figure B-6.--Trial 10.

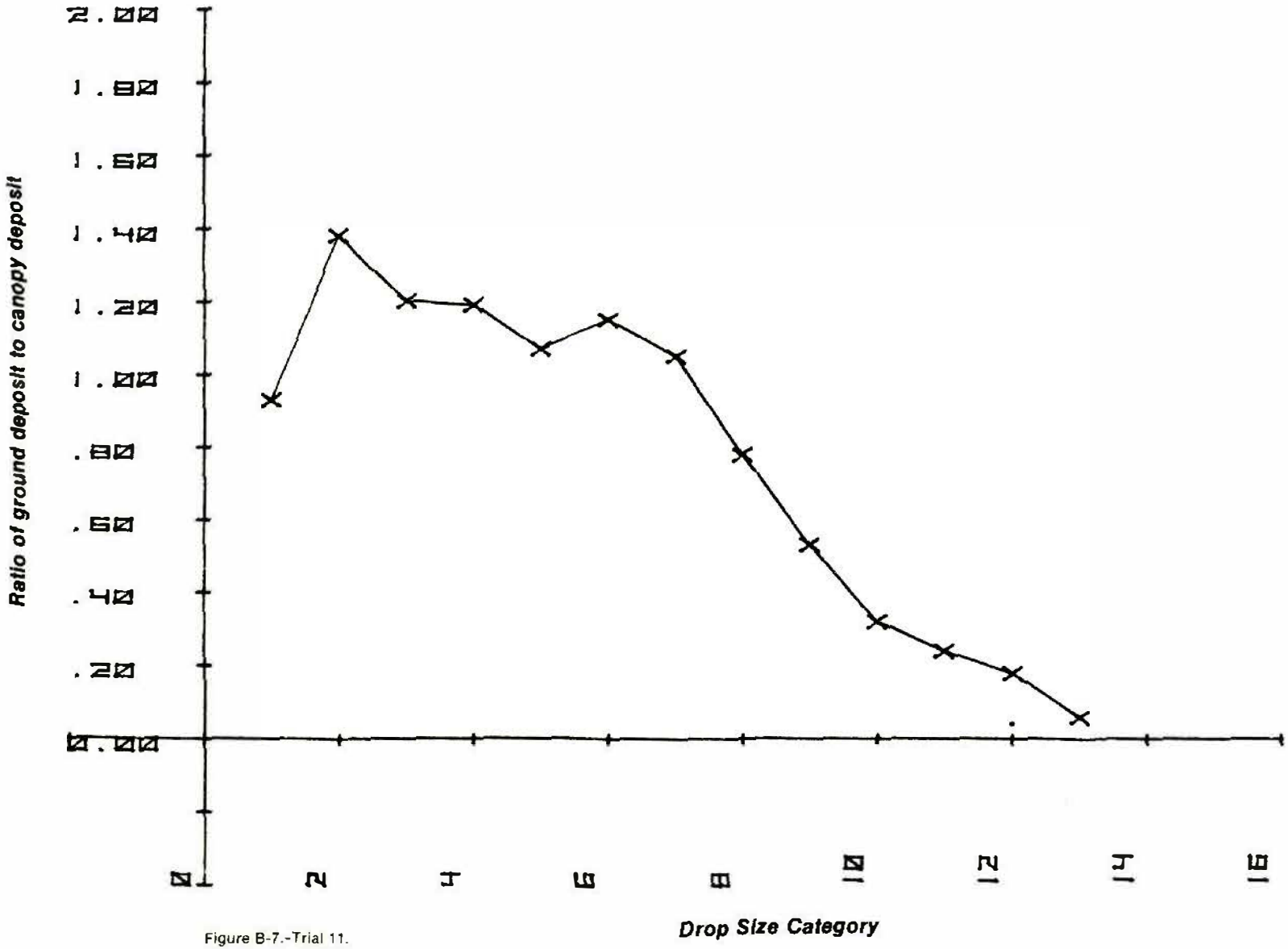


Figure B-7.-Trial 11.

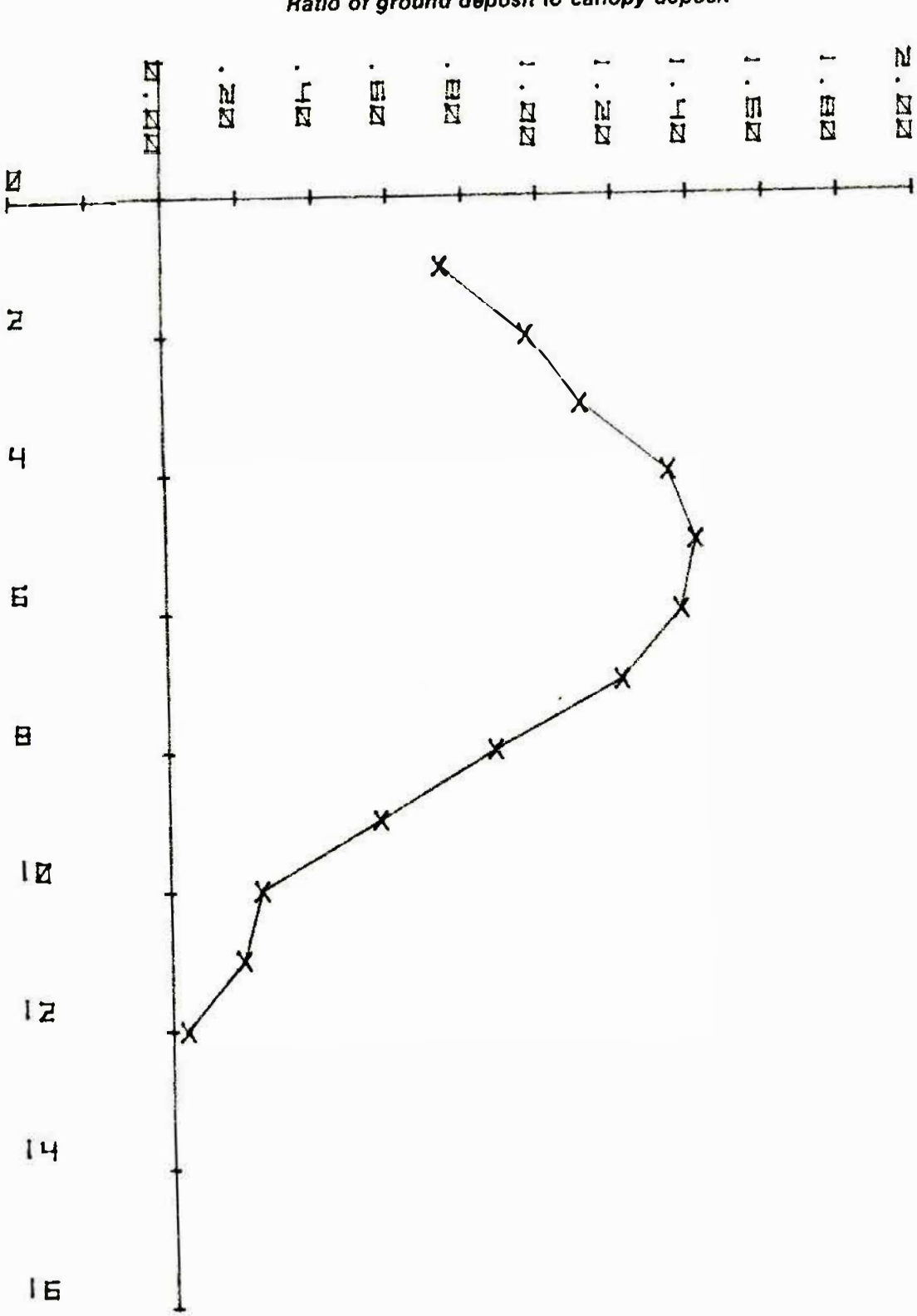


Figure B-8.--Trial 12.

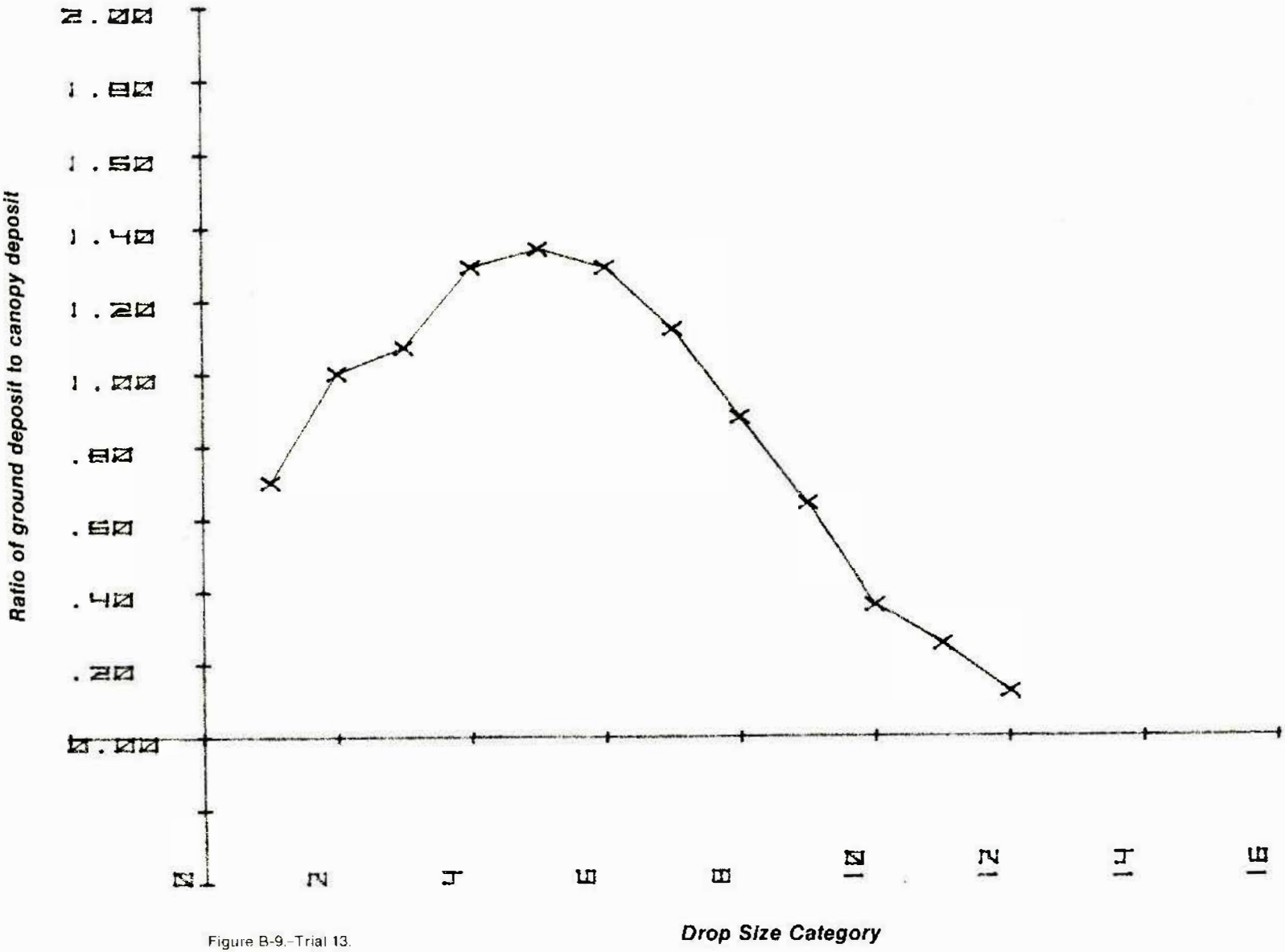


Figure B-9.–Trial 13.

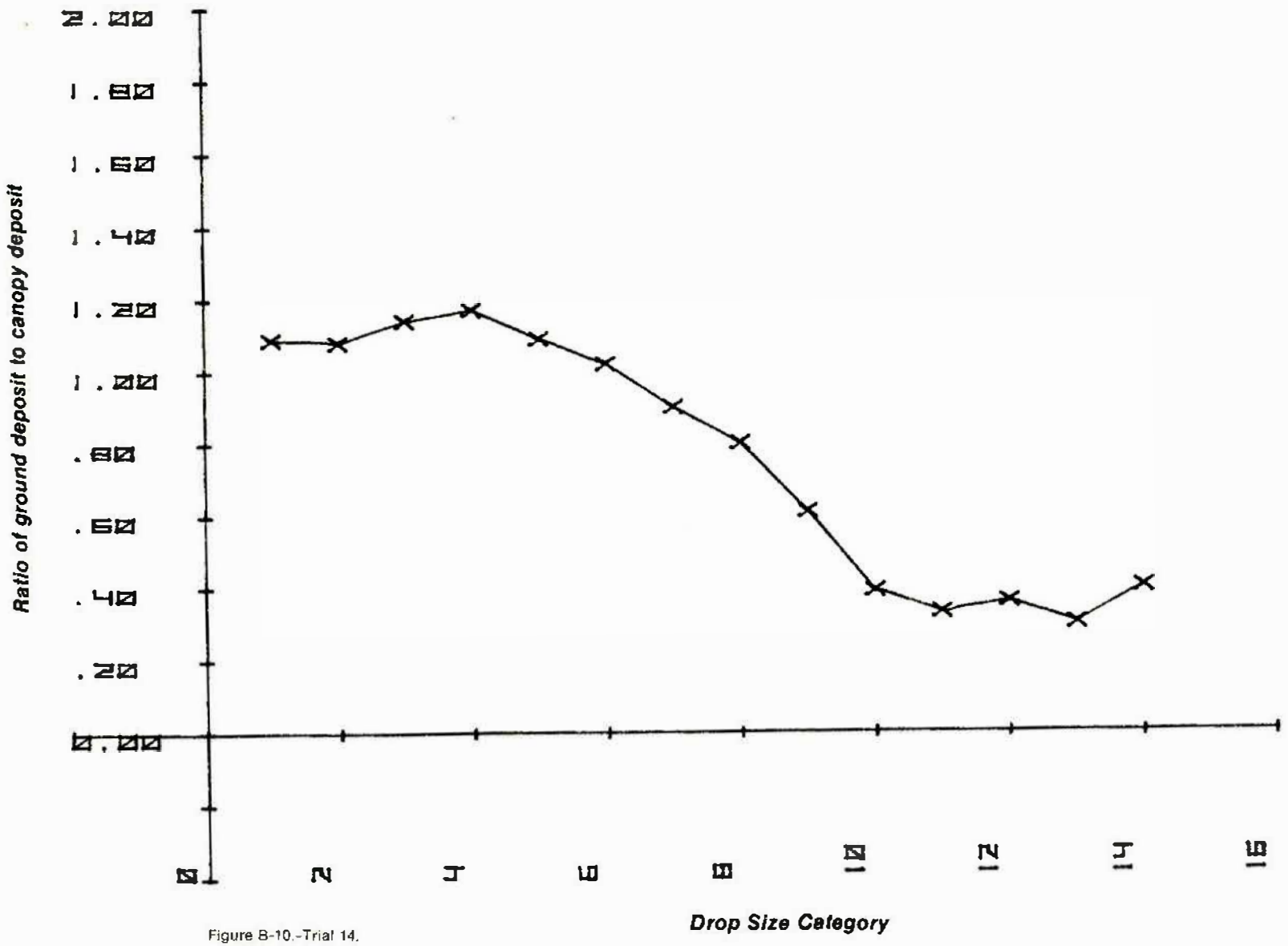


Figure B-10.-Trial 14.

Appendix C
Manganese sulfate recoveries in micrograms, plotted at their relative position in the tree.

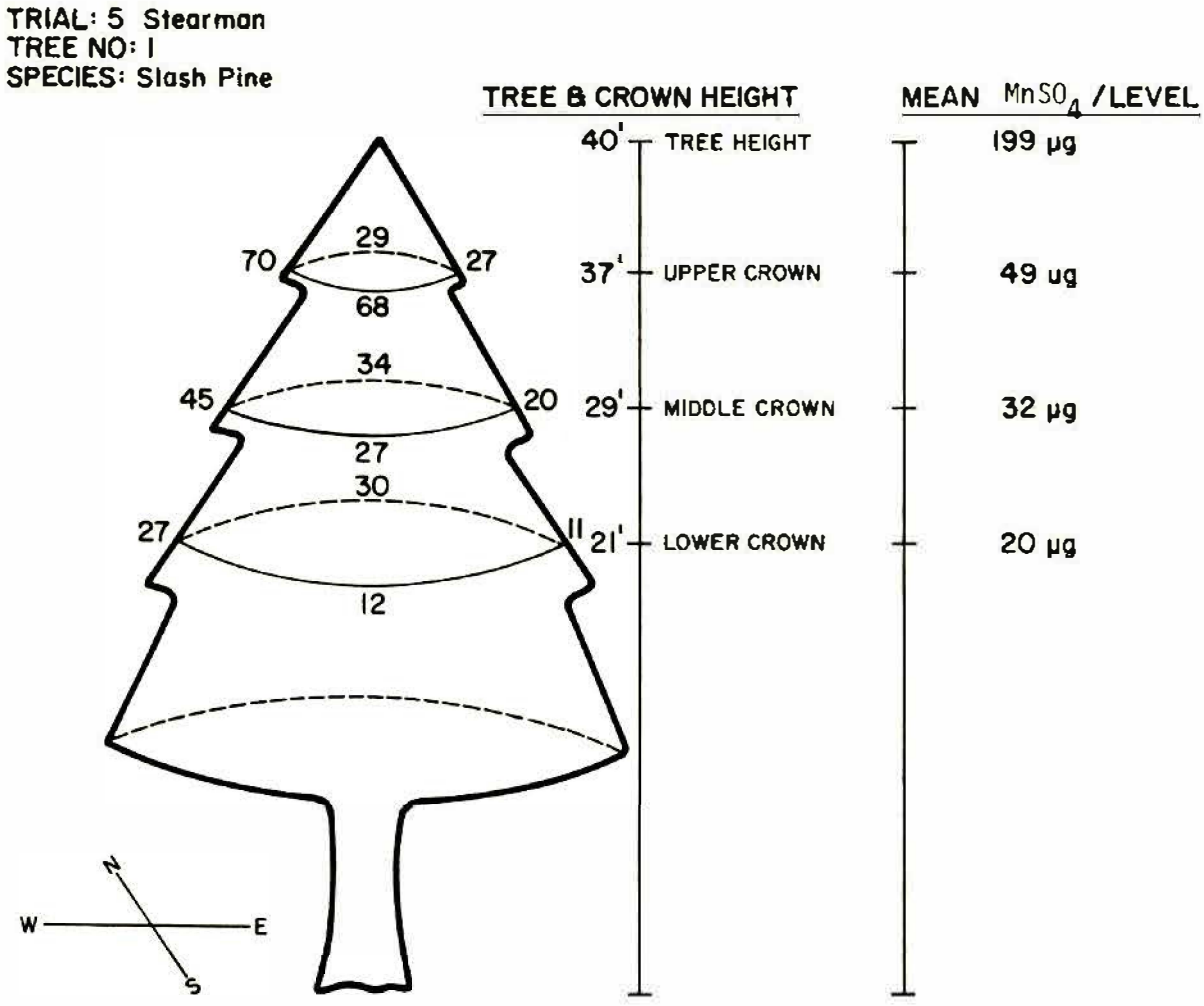
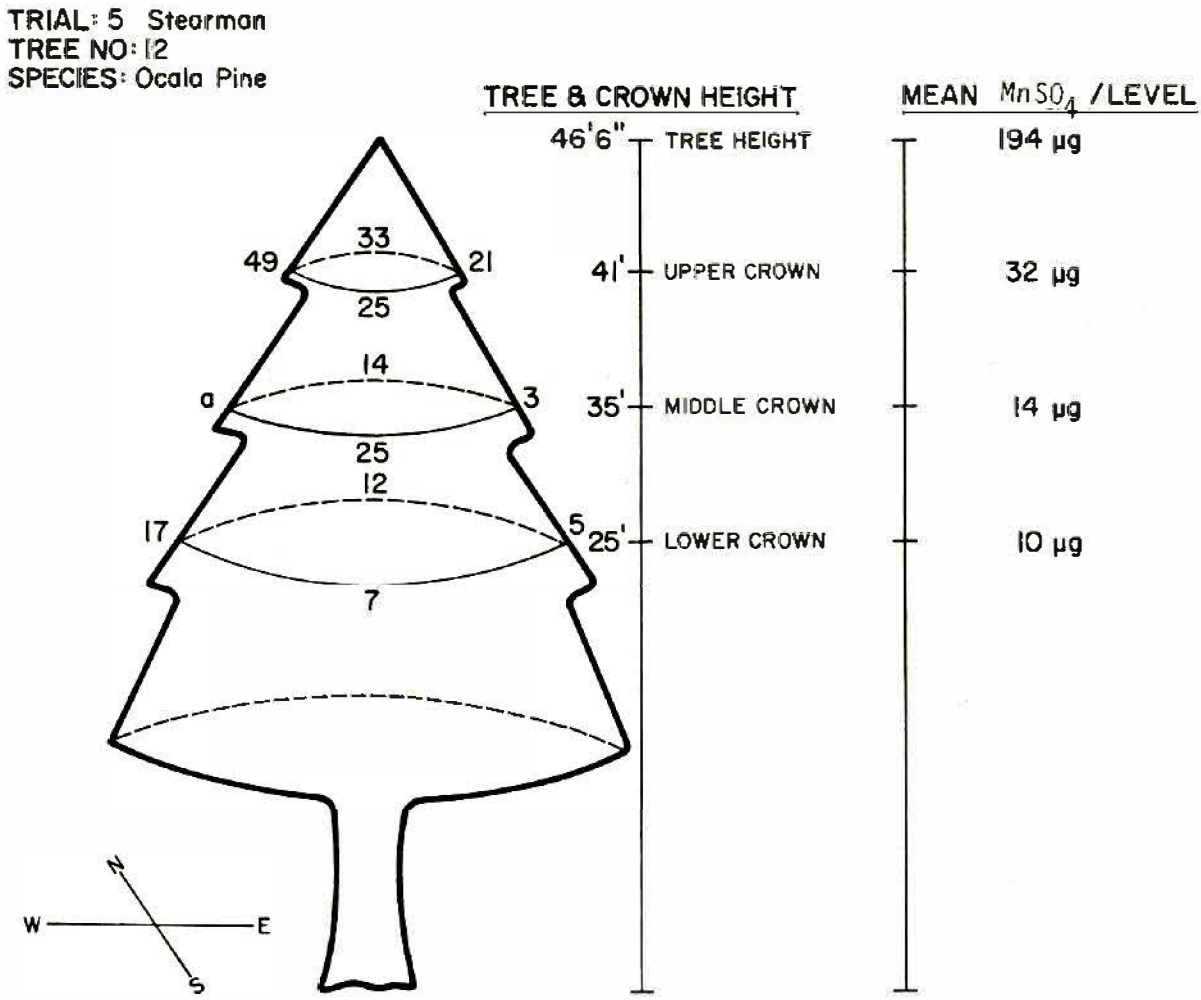


Figure C-1. - Recovery in micrograms of manganese sulfate from cylindrical samplers at each cardinal direction and three crown levels, Withlacoochee State Seed Orchard Project, 1980.



a. Sample possibly contaminated.

Figure C-2. - Recovery in micrograms of manganese sulfate from cylindrical samplers at each cardinal direction and three crown levels, Withlacoochee State Seed Orchard Project, 1980.

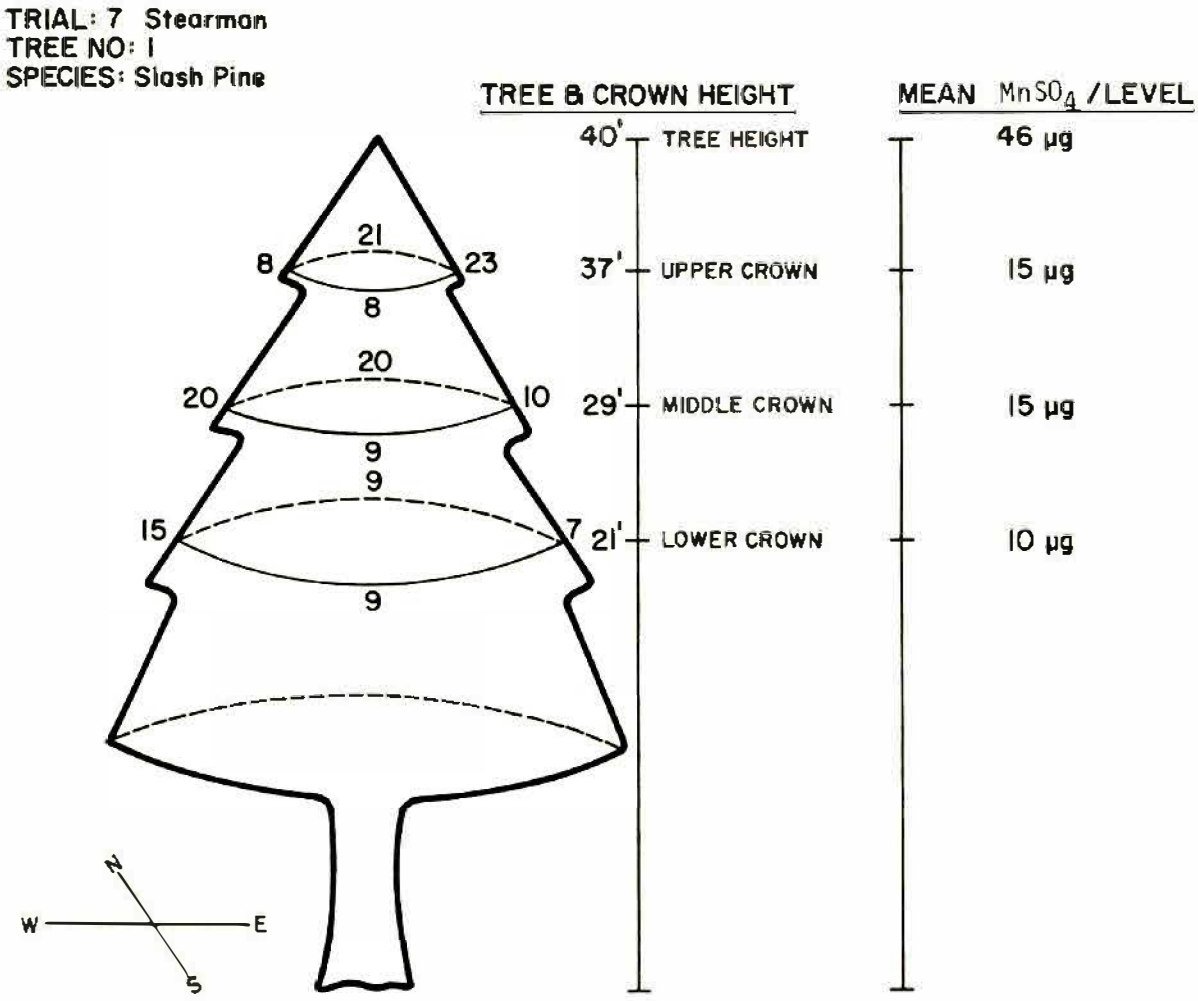
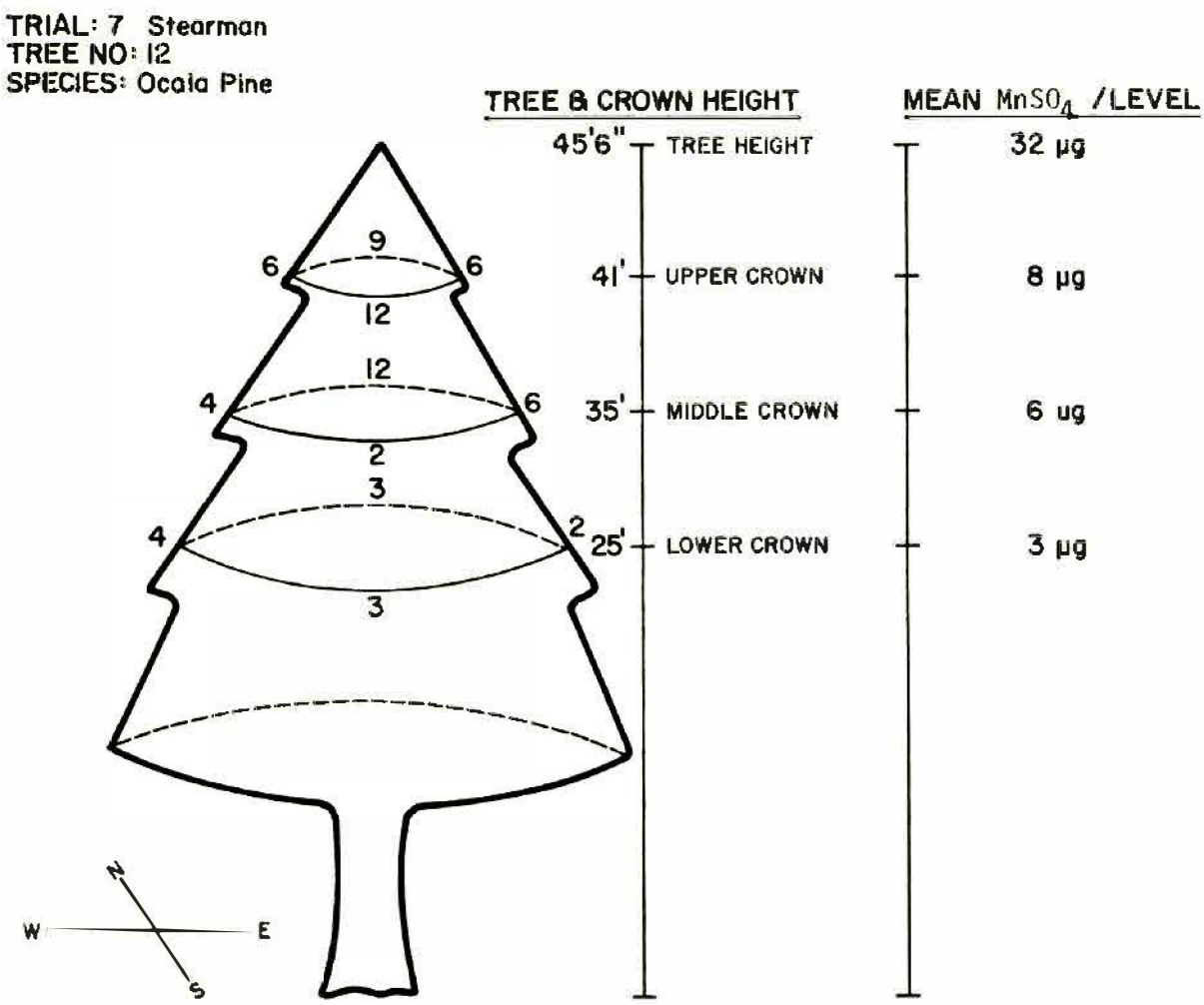


Figure C-3. - Recovery in micrograms of manganese sulfate from cylindrical samplers at each cardinal direction and three crown levels, Withlacoochee State Seed Orchard Project, 1980.



a. Only 15 of 80 gallons was sprayed on this application.

Figure C-4. - Recovery in micrograms of manganese sulfate from cylindrical samplers at each cardinal direction and three crown levels, Withlacoochee State Seed Orchard Project, 1980.

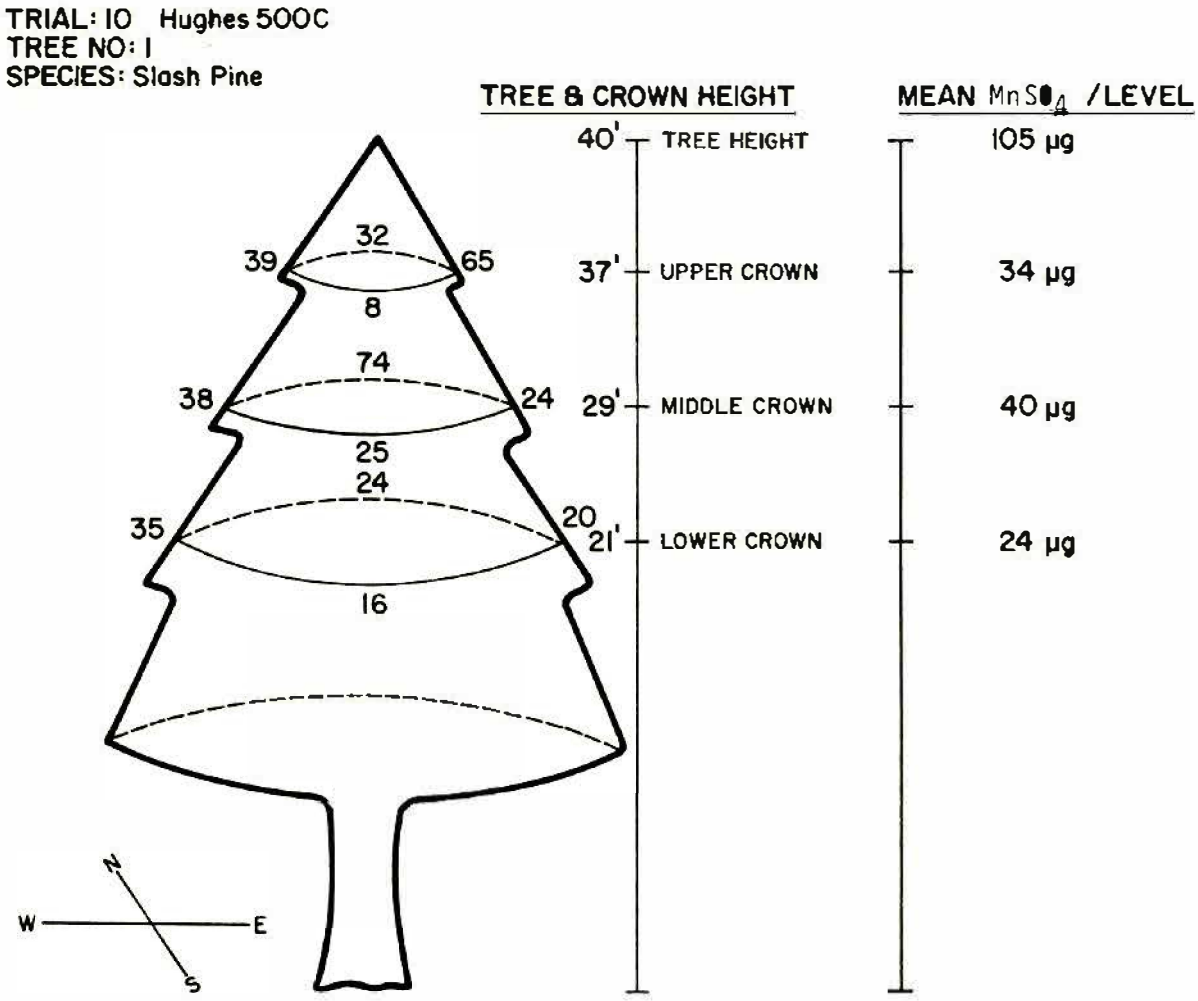


Figure C-5.-Recovery in micrograms of manganese sulfate from cylindrical samplers at each cardinal direction and three crown levels, Withlacoochee State Seed Orchard Project, 1980.

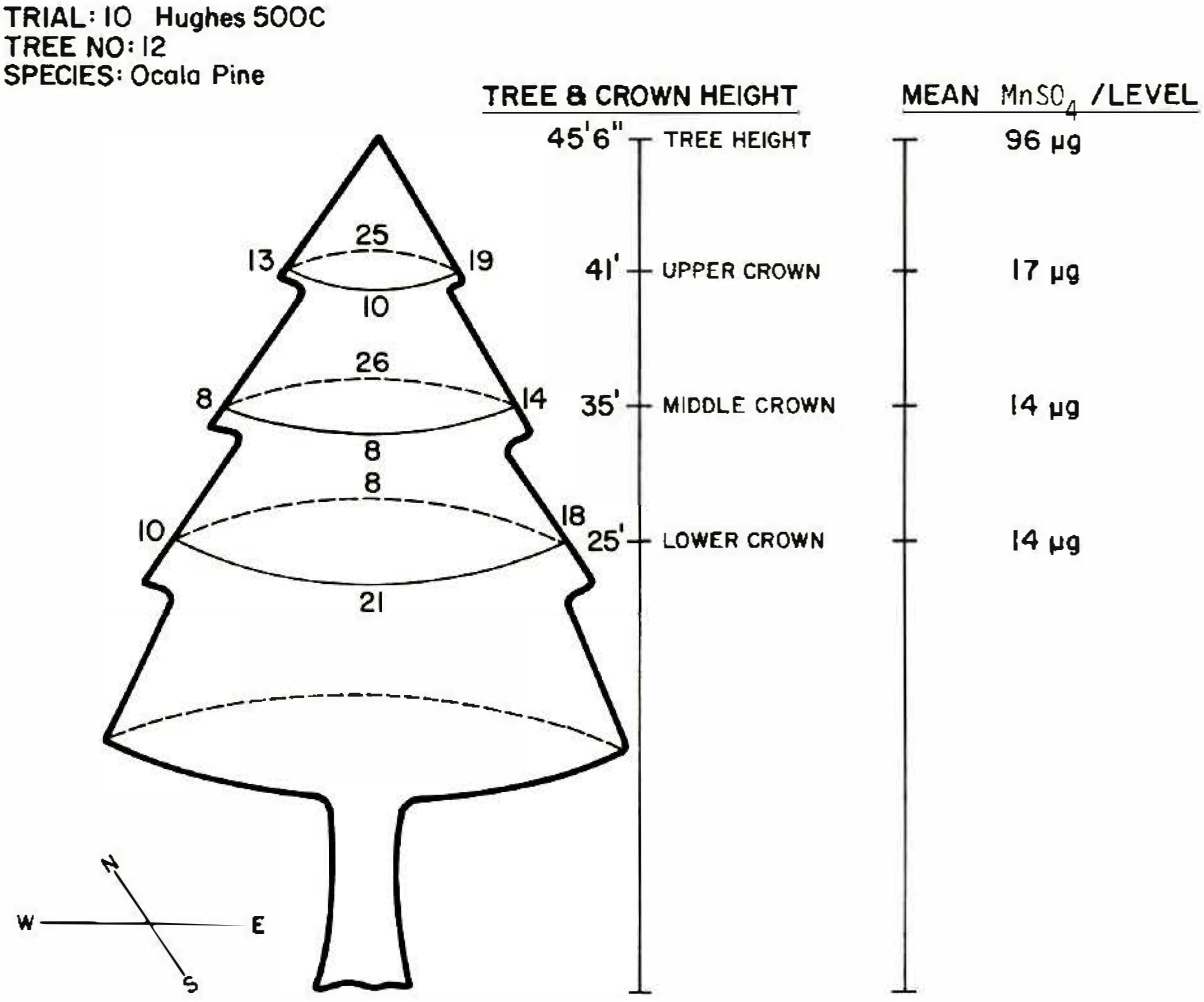


Figure C-6.-Recovery in micrograms of manganese sulfate from cylindrical samplers at each cardinal direction and three crown levels, Withlacoochee State Seed Orchard Project, 1980.

Appendix D

Deposition (drops/cm^2) on sample line stretched across top of canopy perpendicular to direction of spray swaths. Samplers were positioned every 6 feet along sample line.

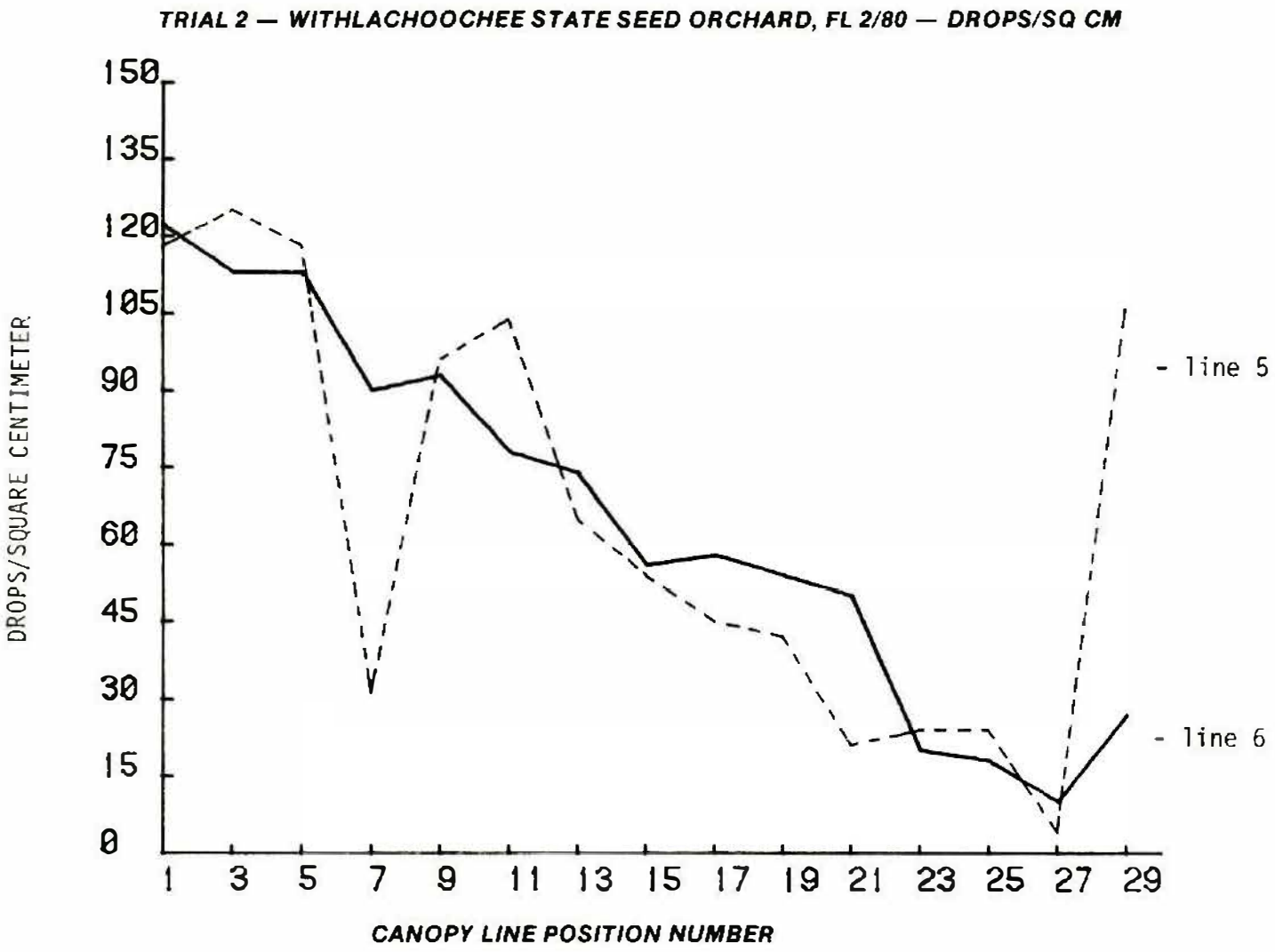


Figure D-1 — Trial 2, deposition on top of cylinder positioned 5 feet below release height.

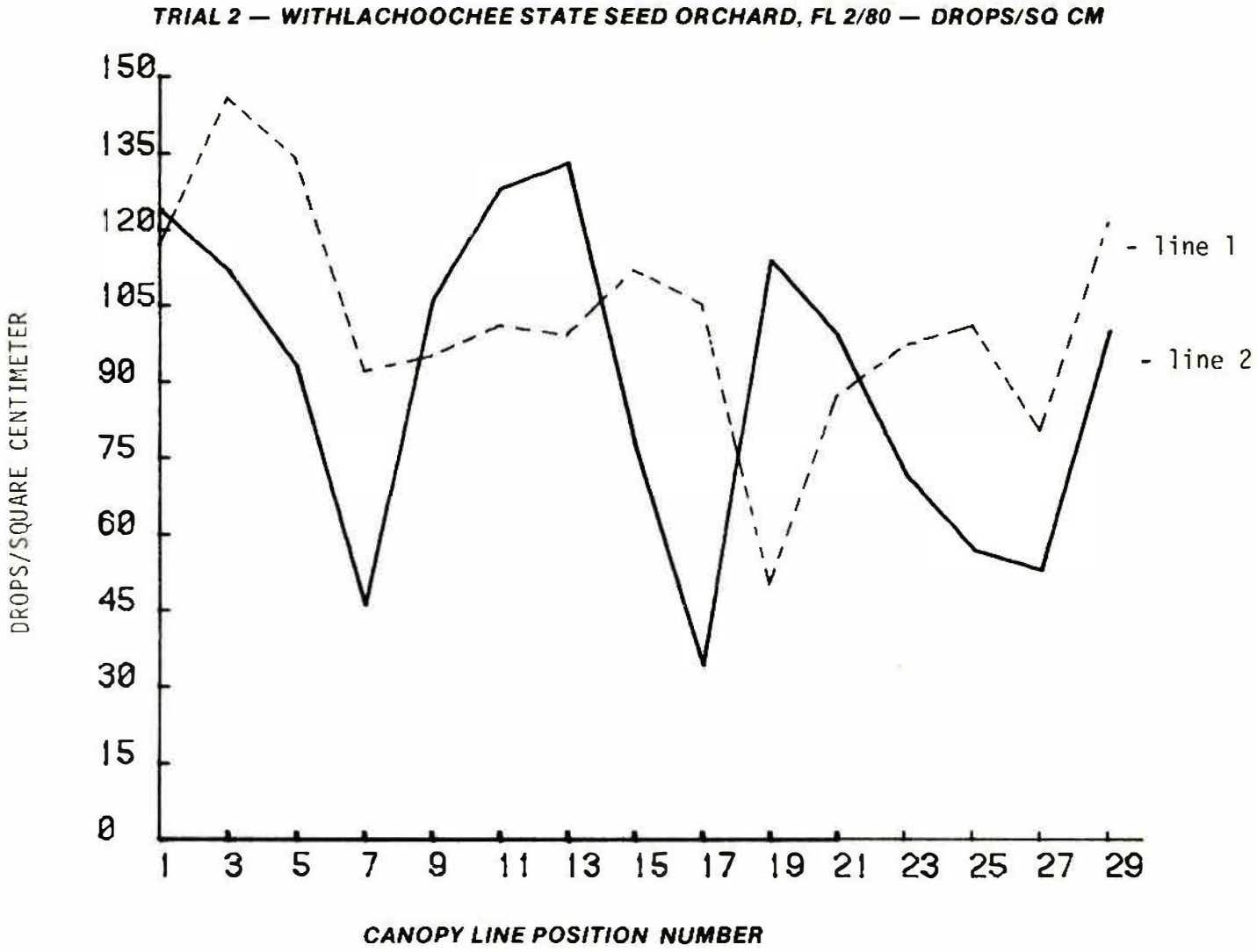


Figure D-2 - Trial 2, deposition on top of cylinder positioned 5 feet below release height.

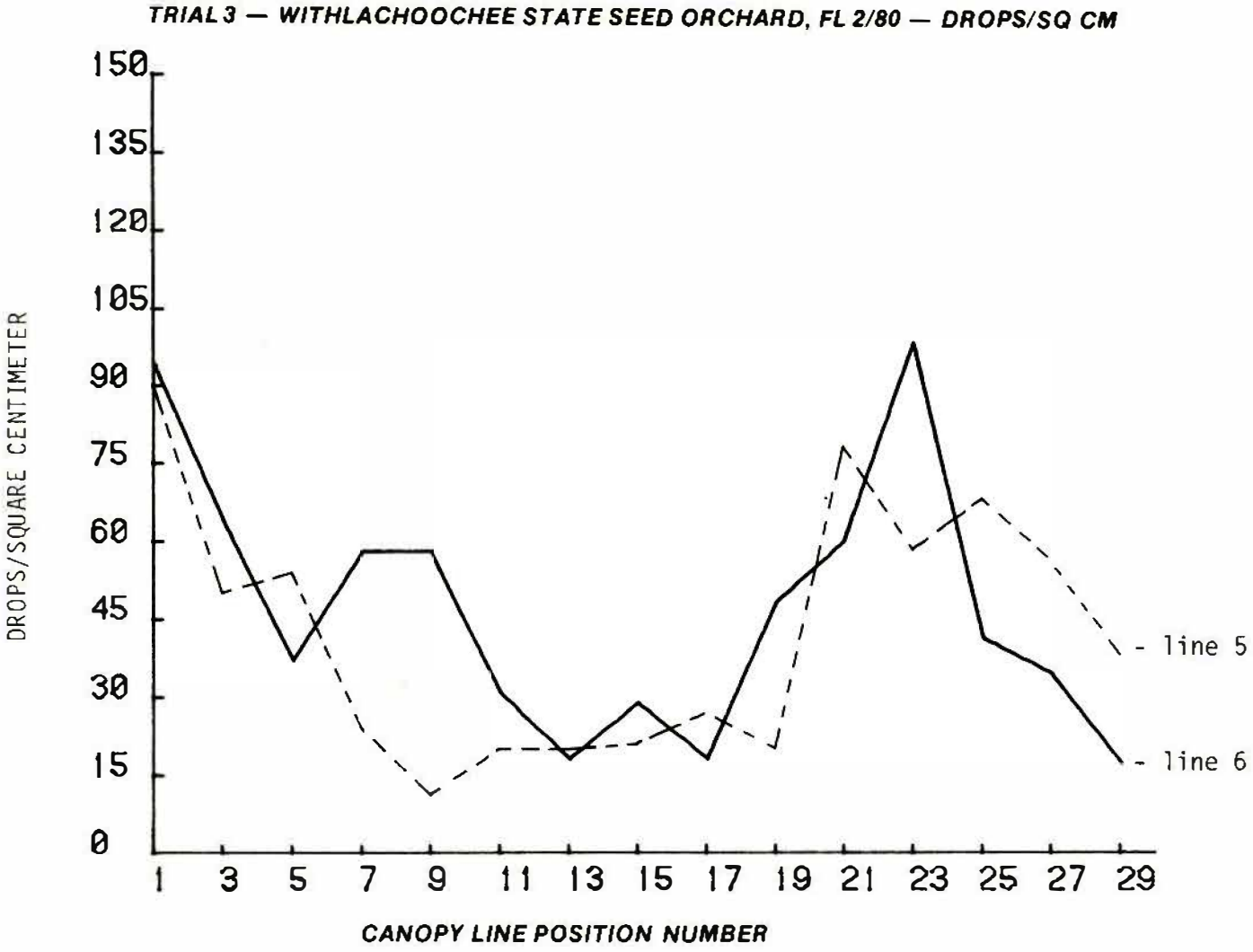


Figure D-3.-Trial 3, deposition on top of cylinder positioned 5 feet below release height.

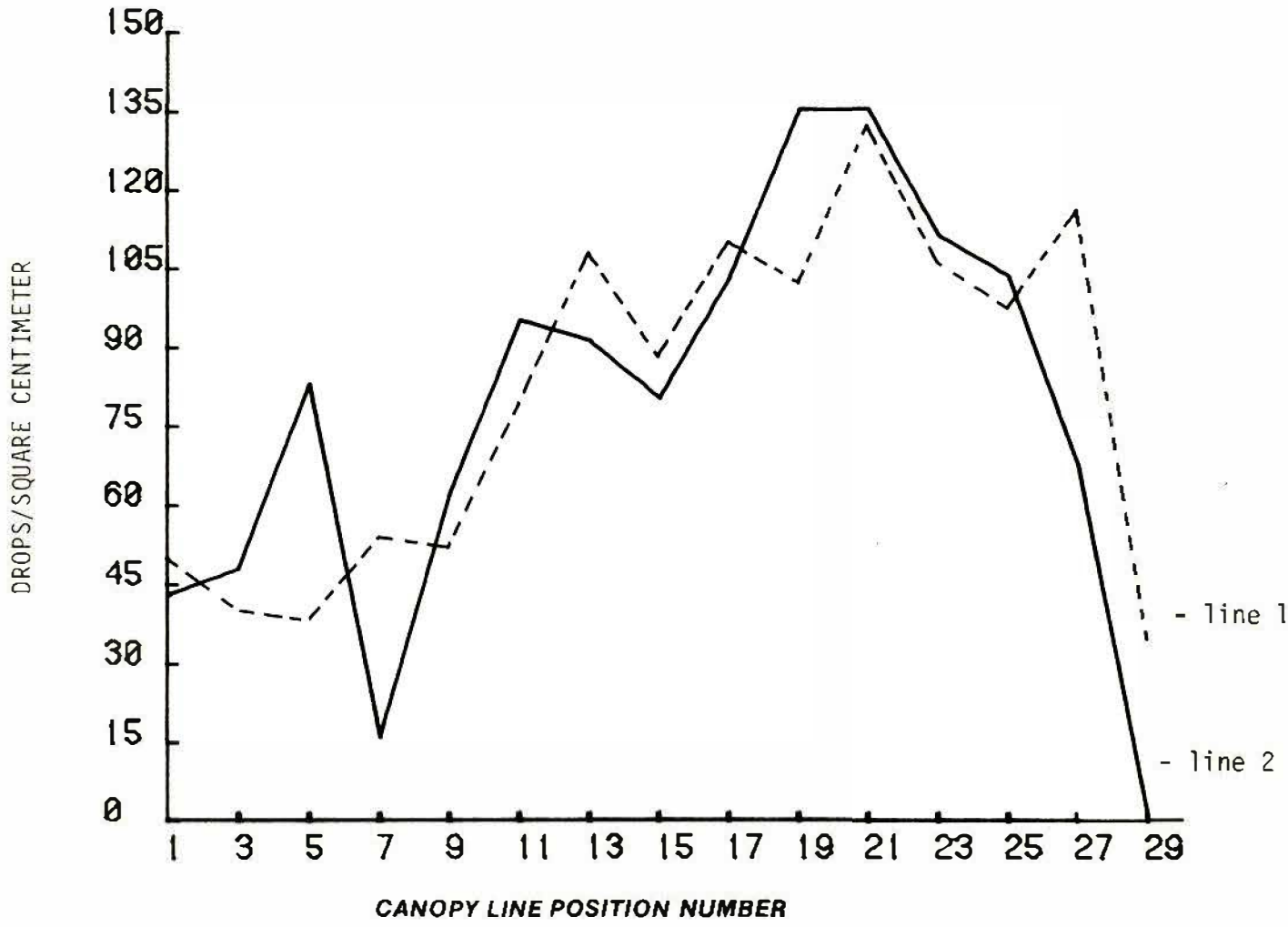


Figure B-4. — Trial 3, deposition on top of cylinder positioned 5 feet below release height.

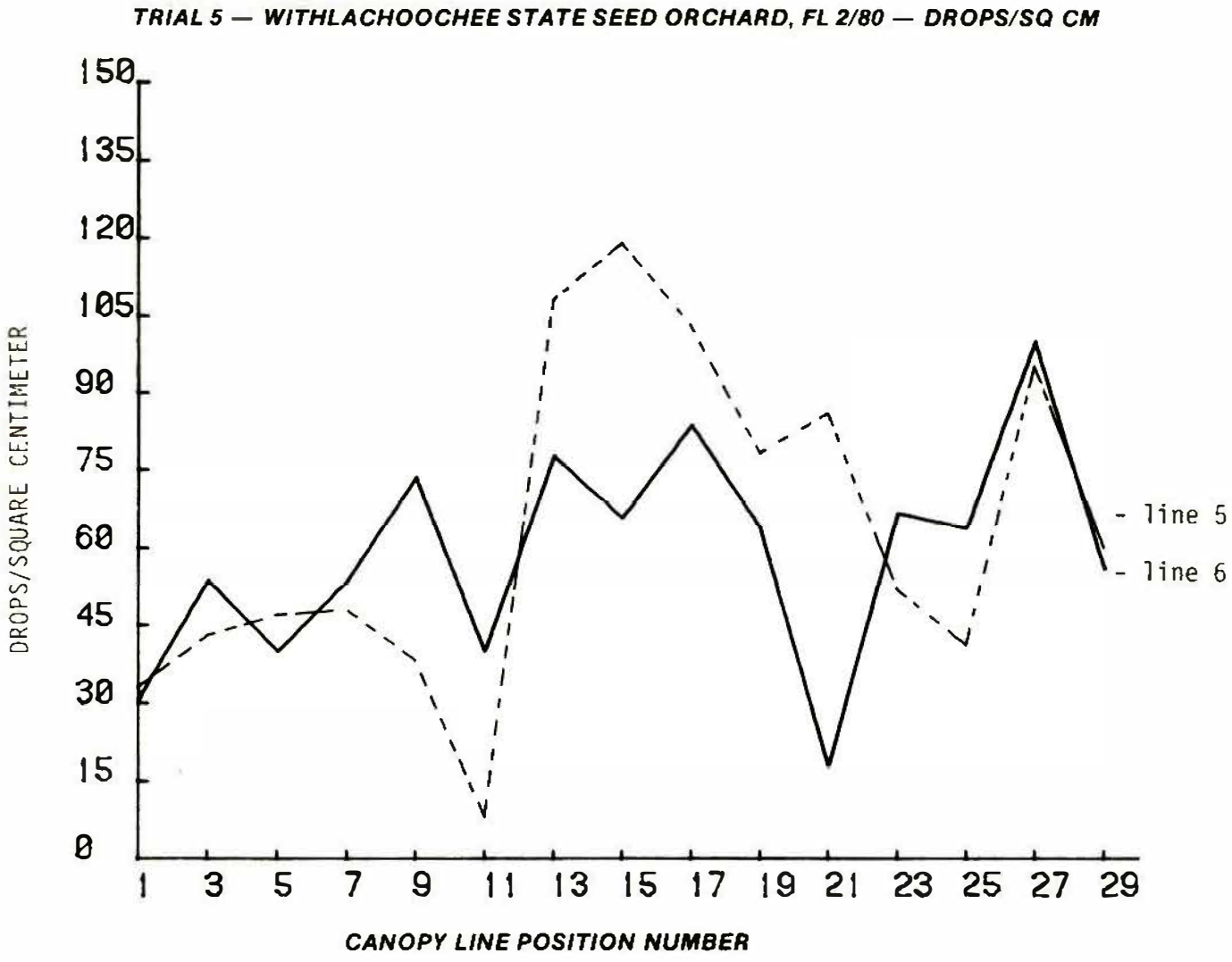


Figure D-5. — Trial 5, deposition on top of cylinder positioned 5 feet below release height.

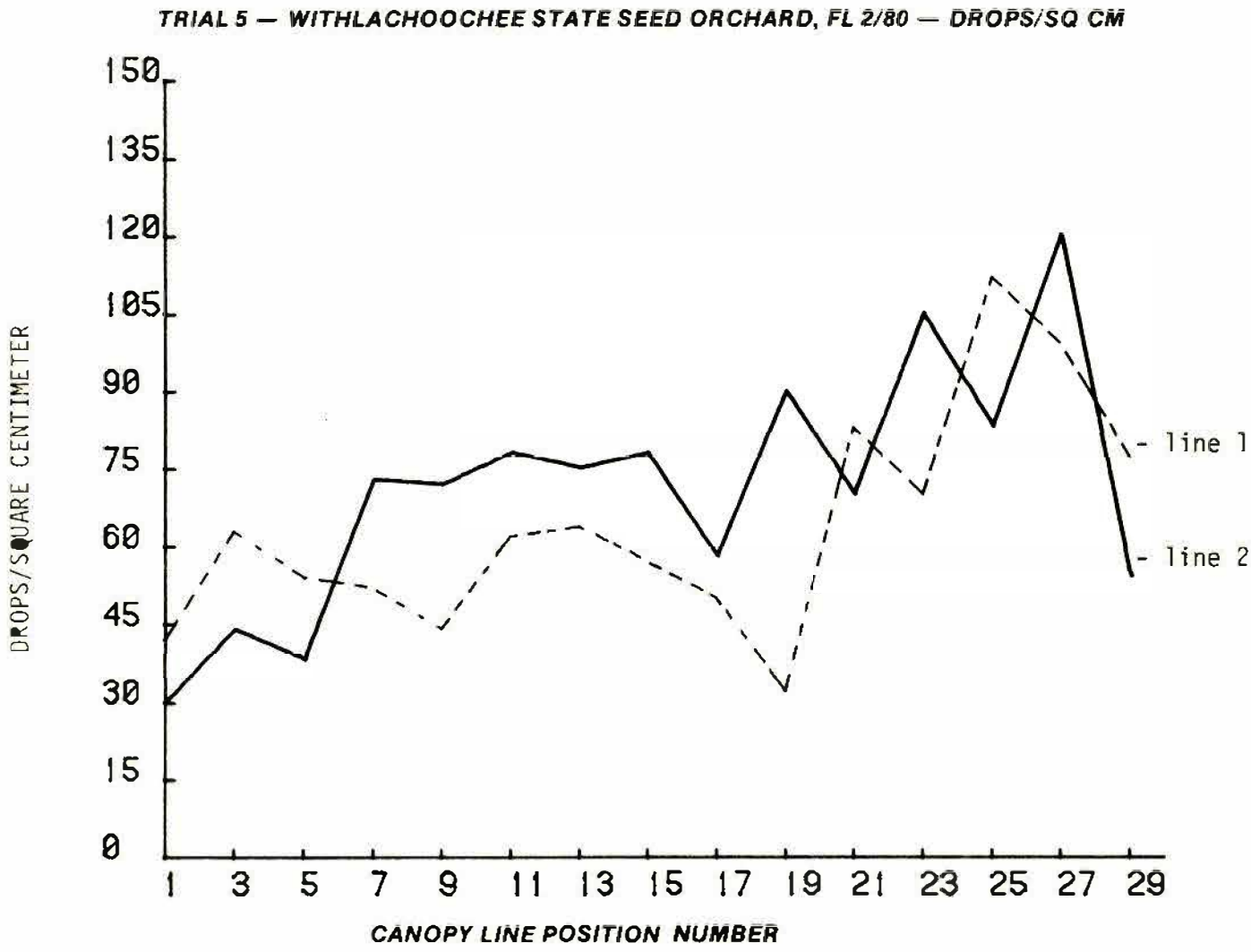


Figure D-6. — Trial 5, deposition on top of cylinder positioned 5 feet below release height.

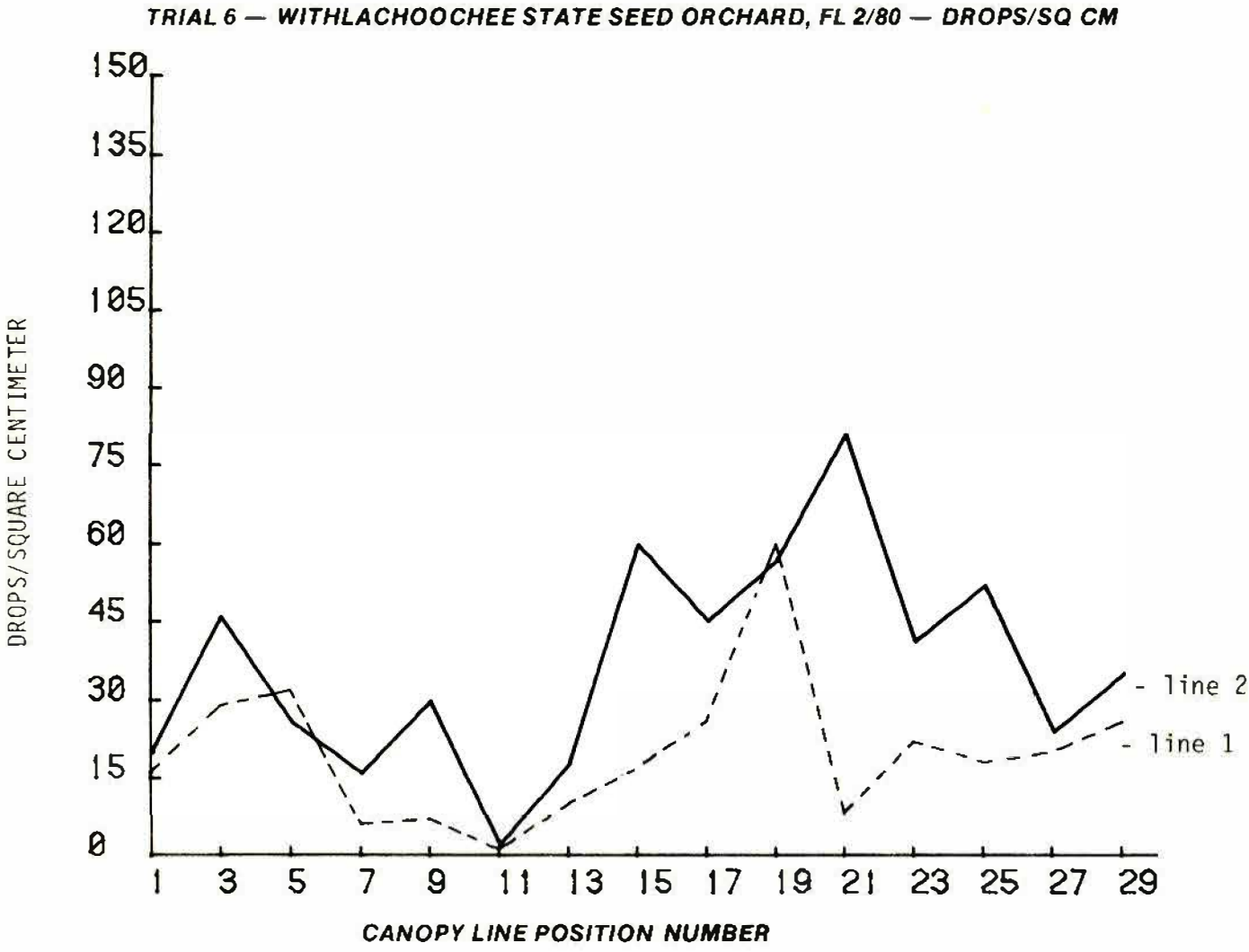


Figure D-7. — Trial 6, deposition on top of cylinder positioned 5 feet below release height.

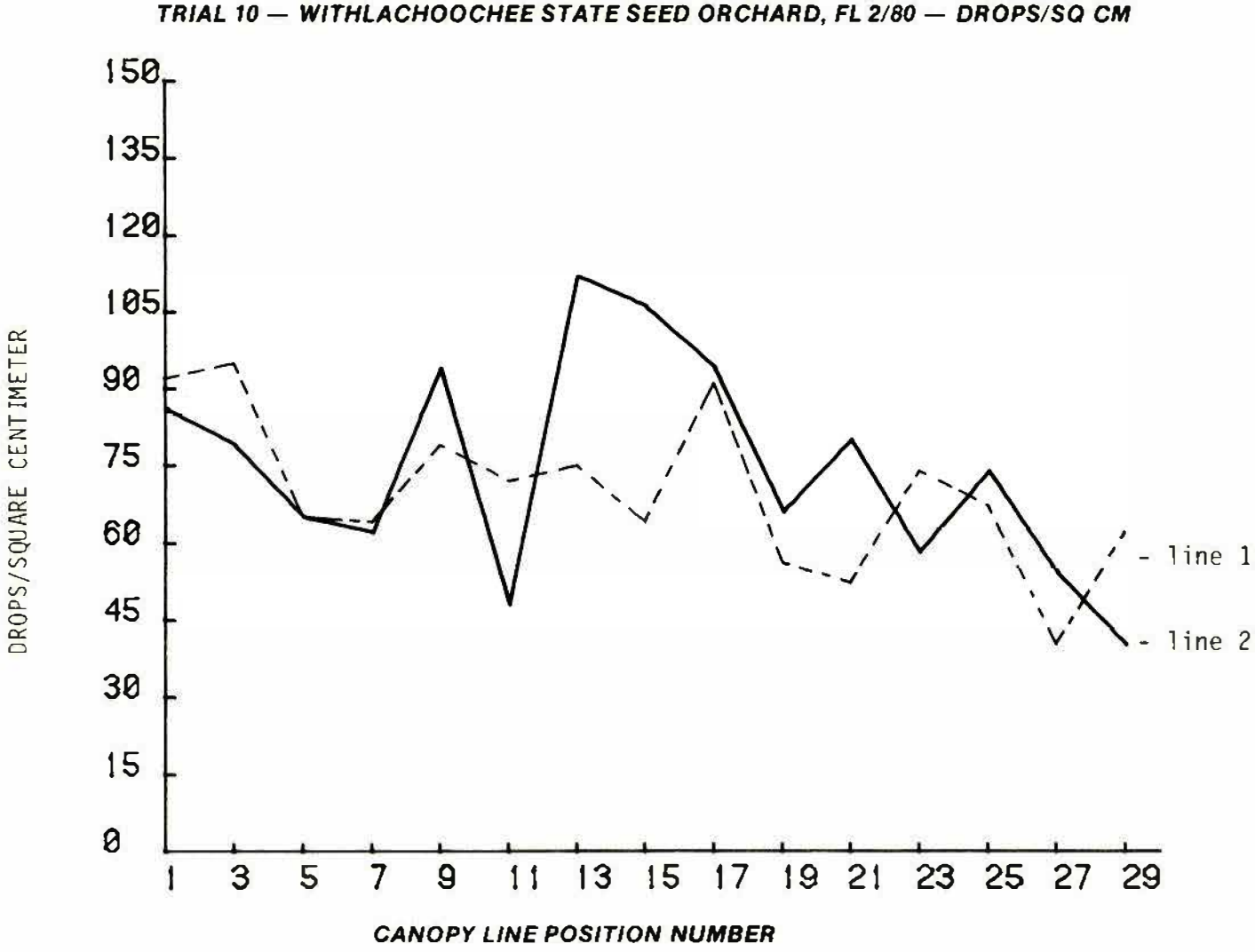


Figure D-8. — Trial 10, deposition on top of cylinder positioned 5 feet below release height.

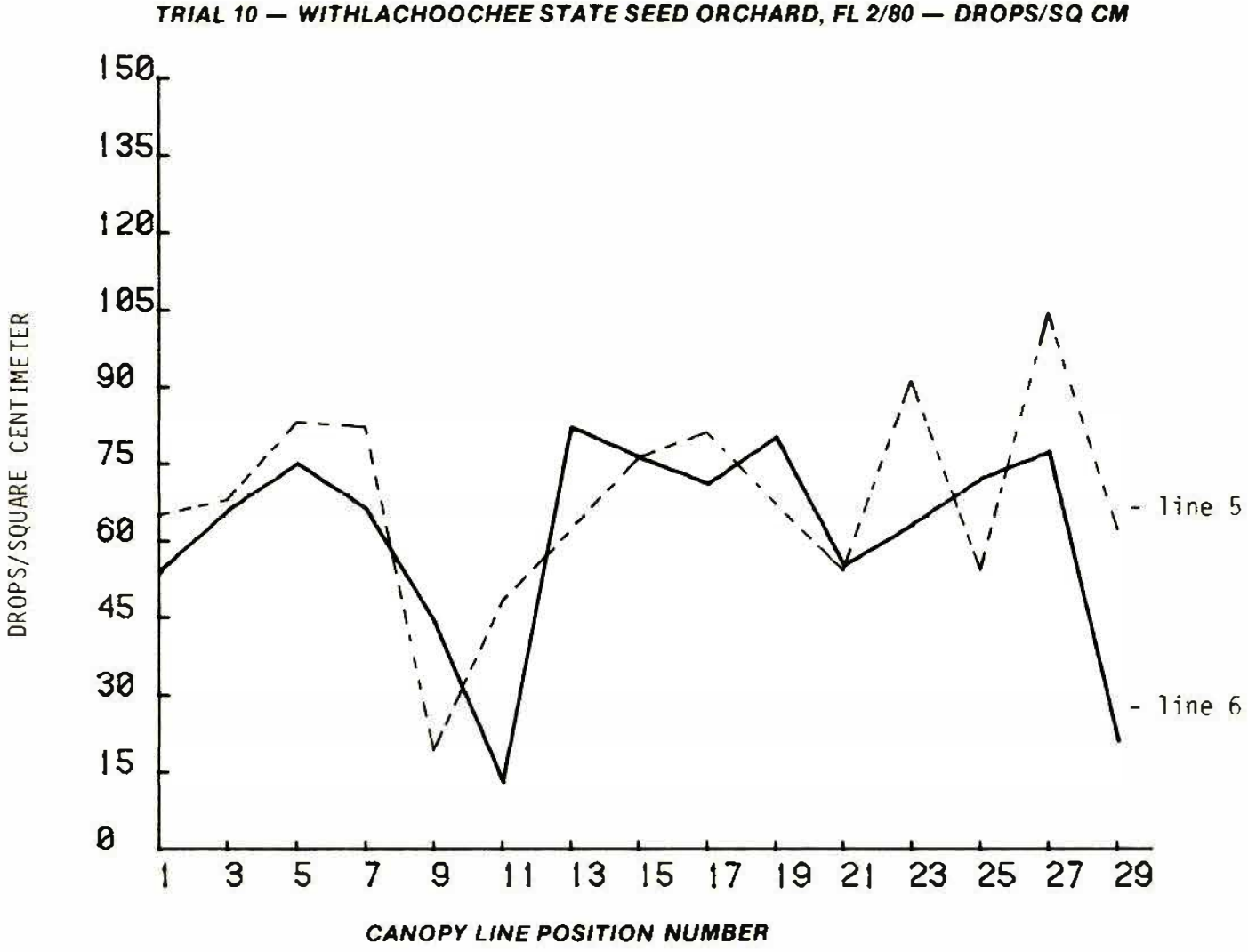


Figure D-9. — Trial 10, deposition on top of cylinder positioned 5 feet below release height.

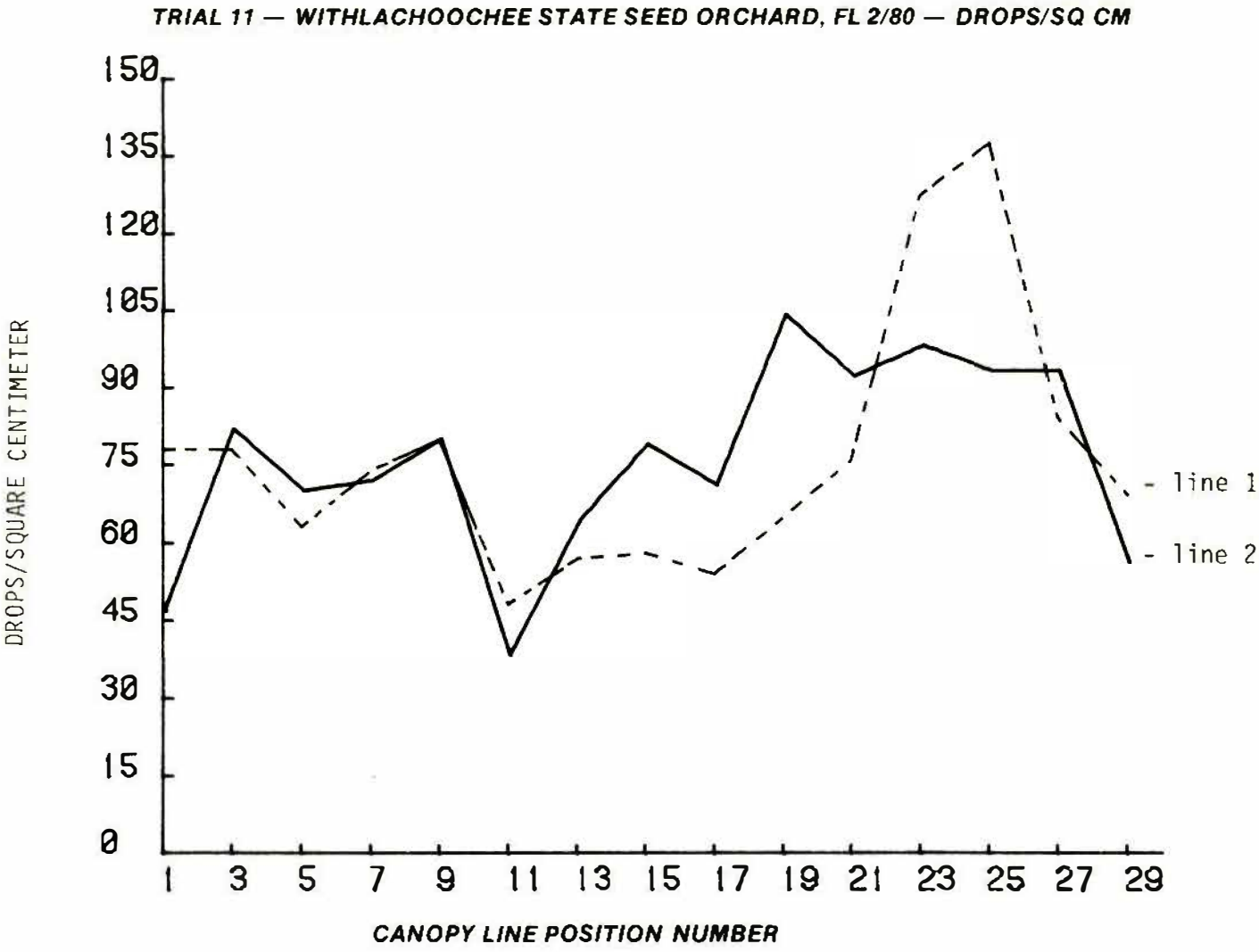


Figure D-10. — Trial 11, deposition on top of cylinder positioned 5 feet below release height.

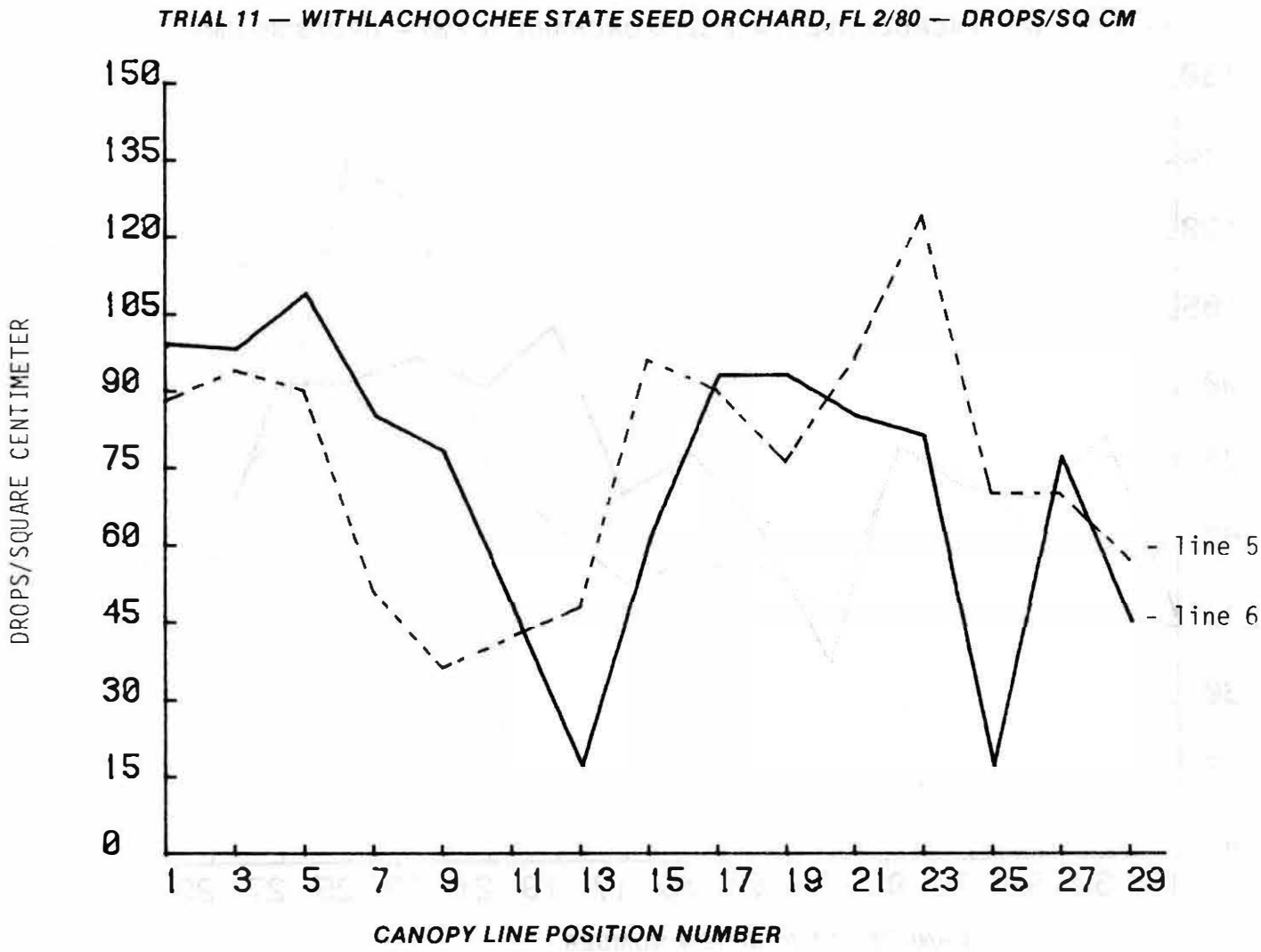


Figure D-11. — Trial 11, deposition on top of cylinder positioned 5 feet below release height.

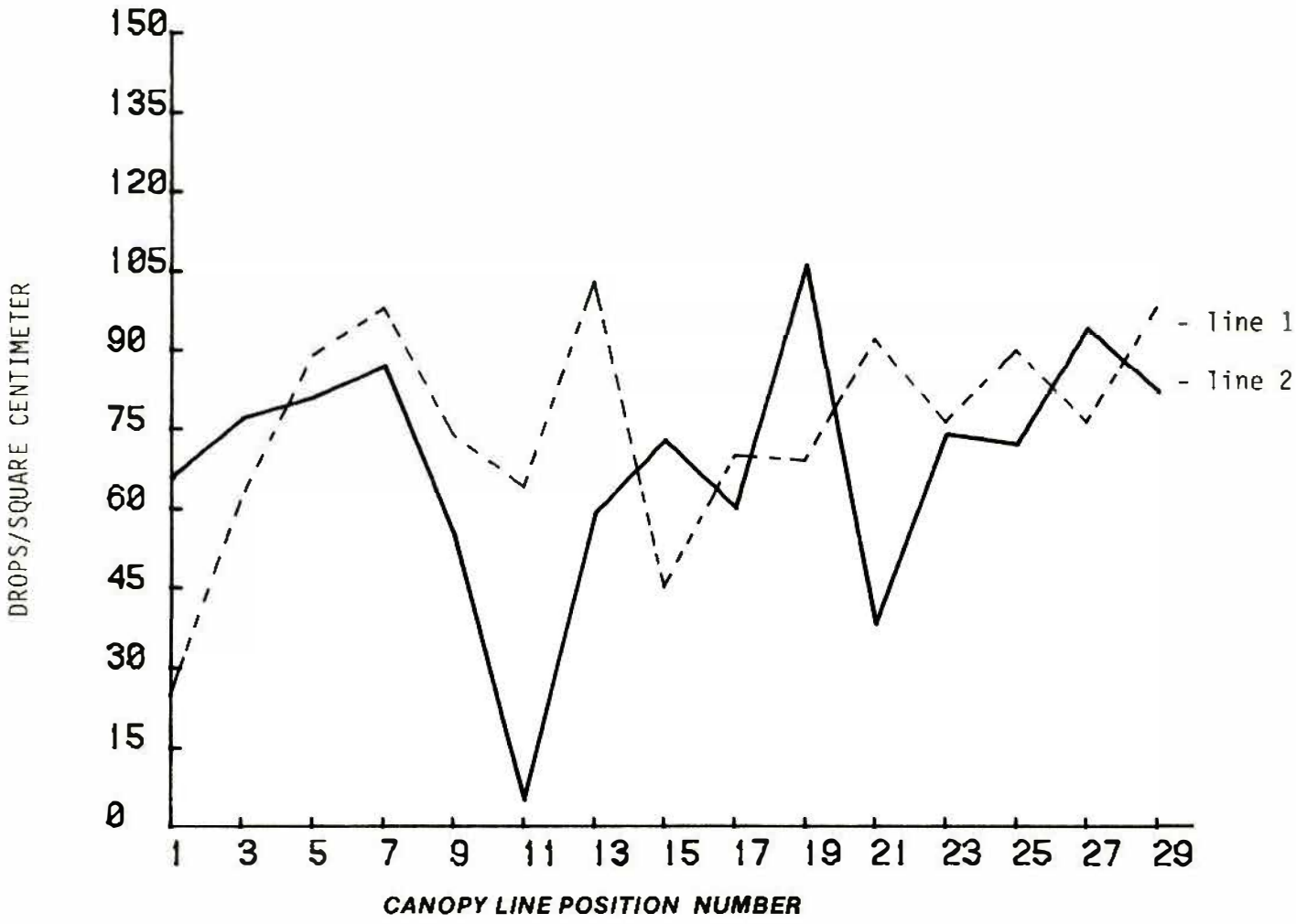


Figure D-12. — Trial 12, deposition on top of cylinder positioned 5 feet below release height.

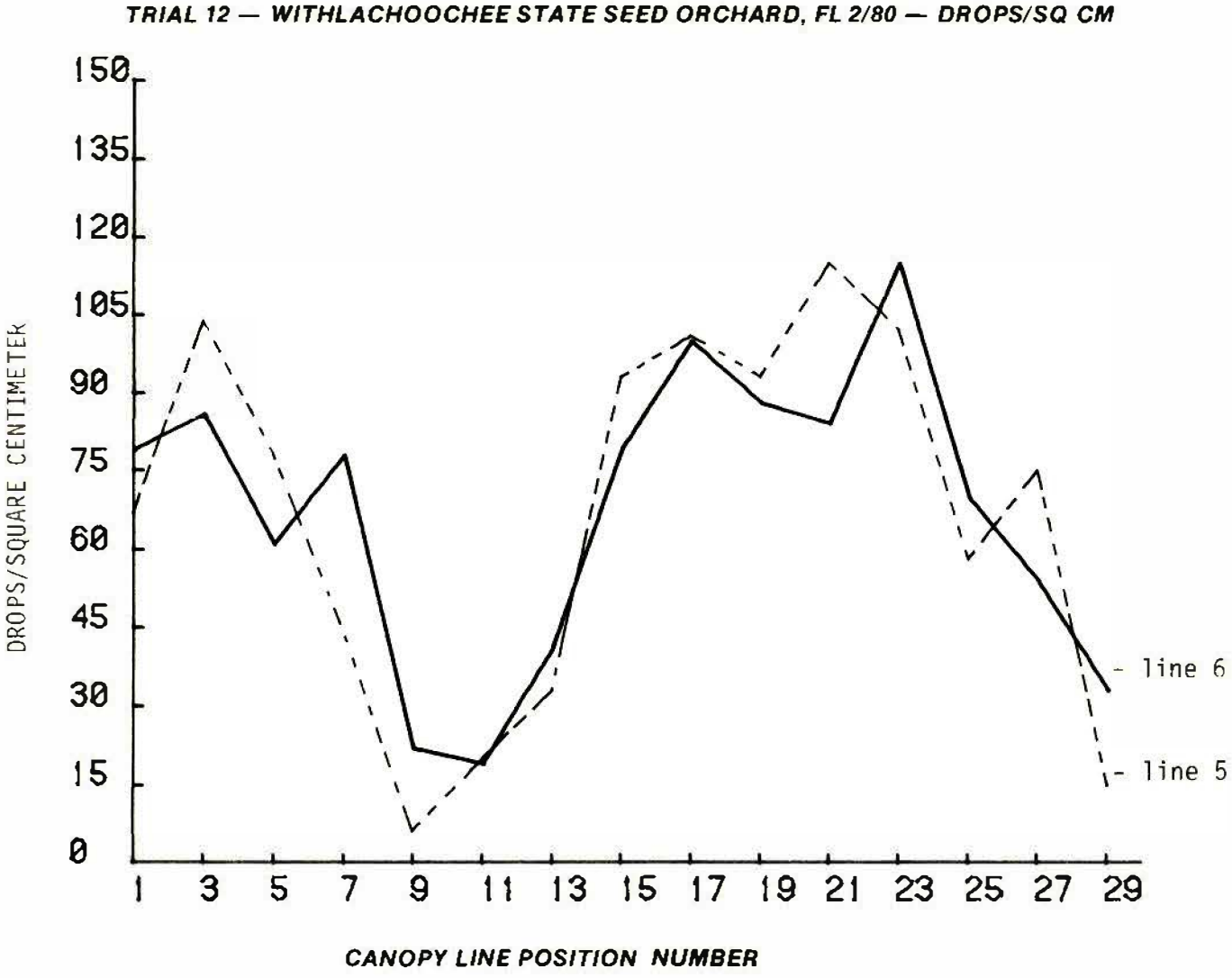


Figure B-13. — Trial 12, deposition on top of cylinder positioned 5 feet below release height.

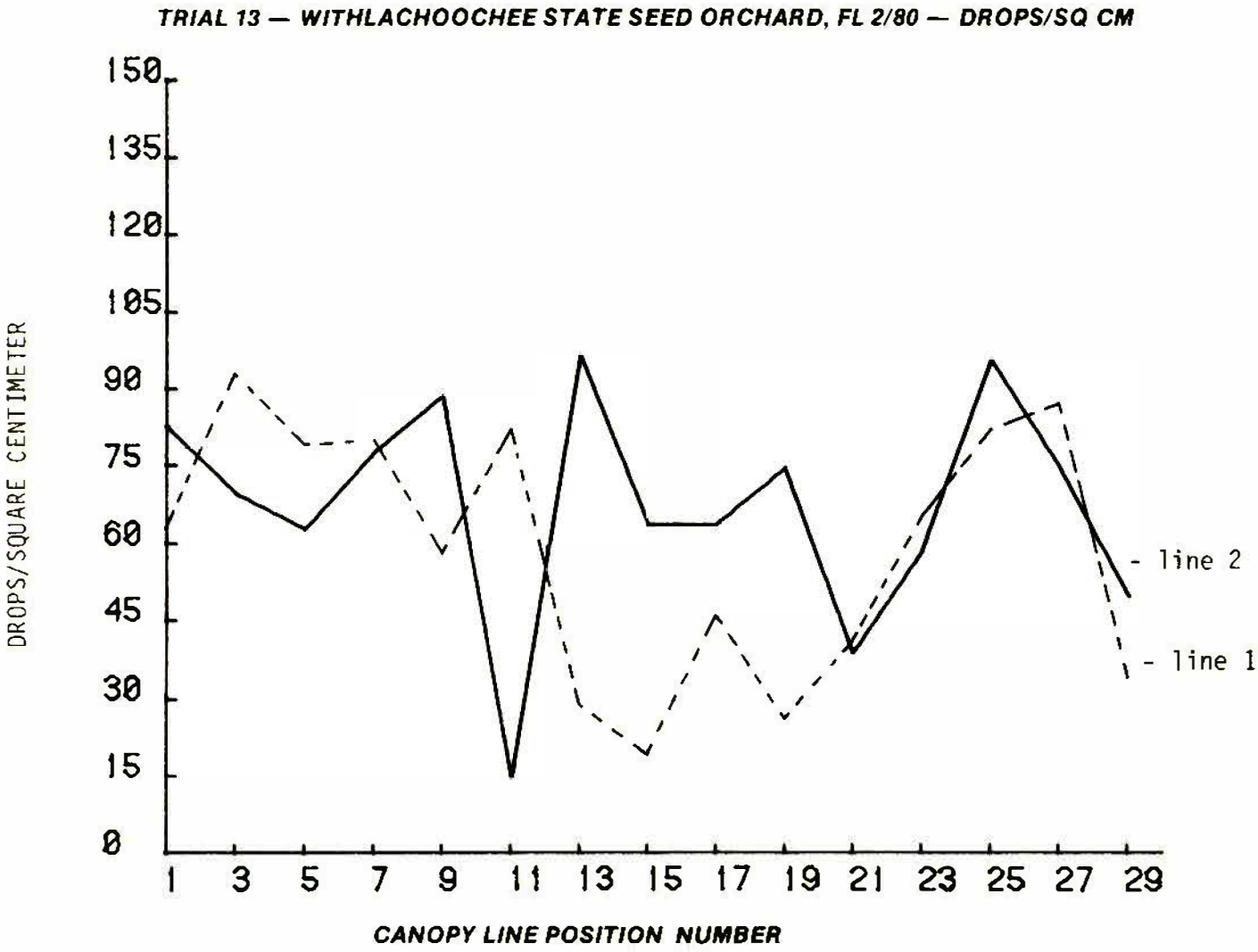


Figure D-14. — Trial 13, deposition on top of cylinder positioned 5 feet below release height.

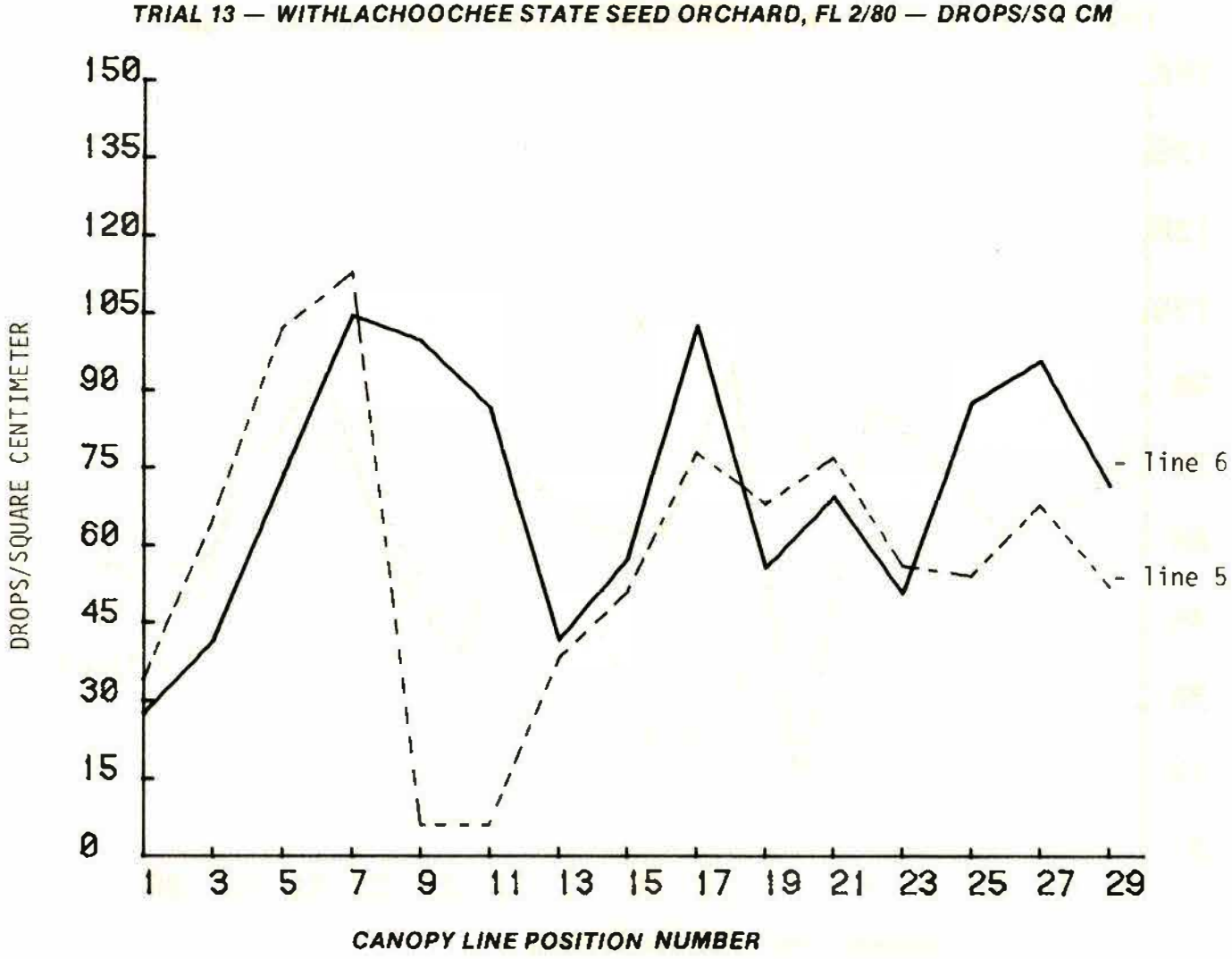


Figure D-15. — Trial 13, deposition on top of cylinder positioned 5 feet below release height.

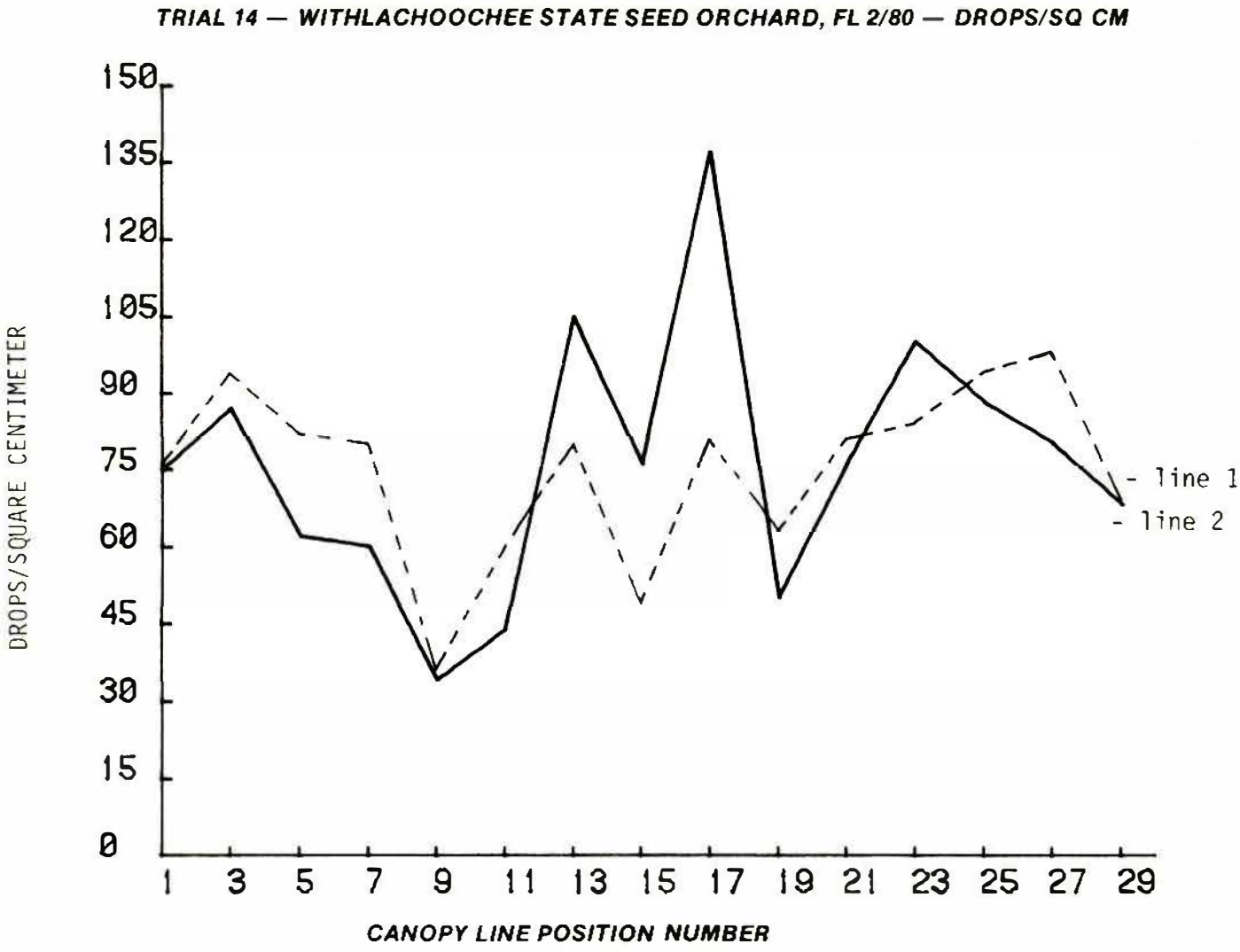


Figure D-16. — Trial 14, deposition on top of cylinder positioned 5 feet below release height.

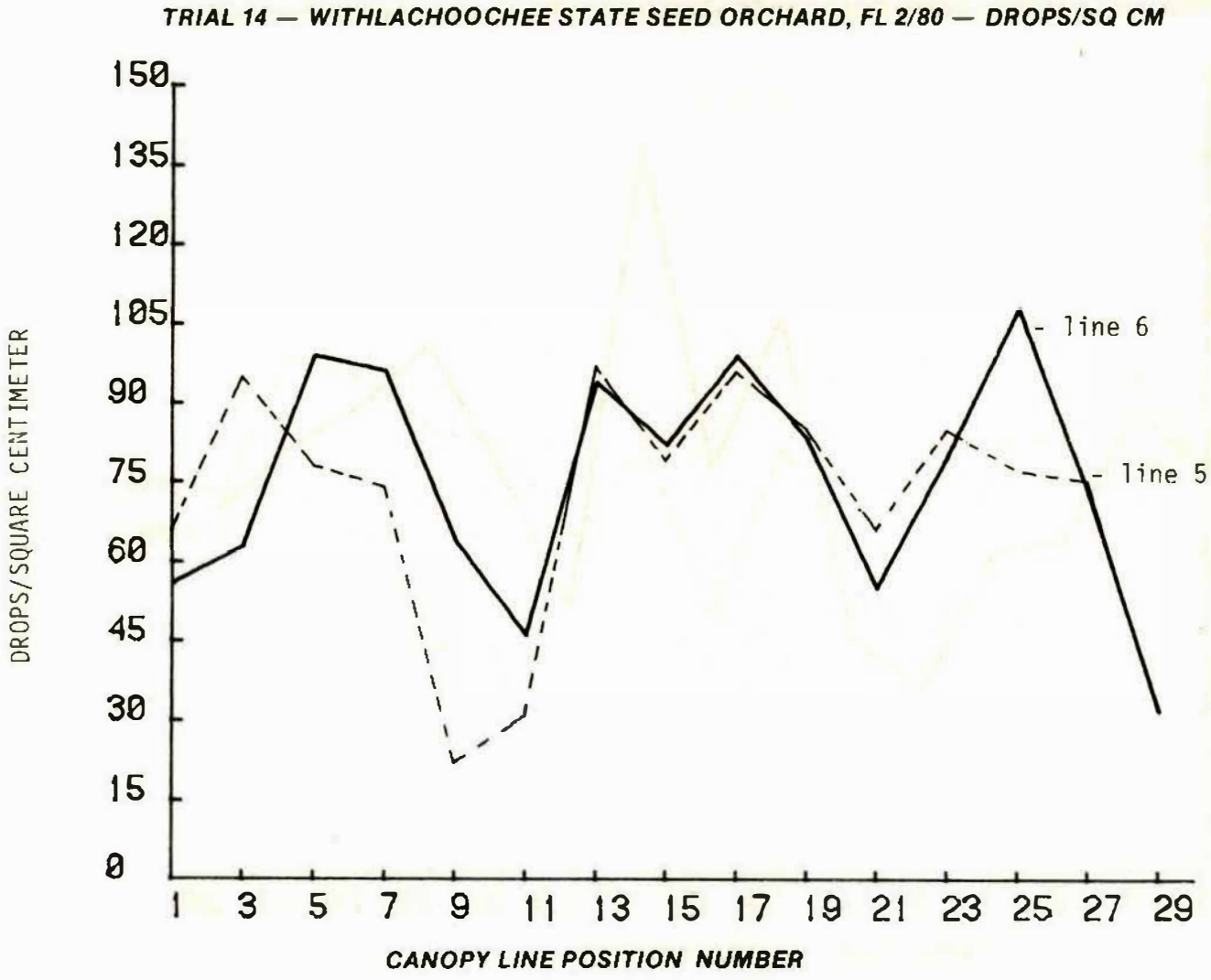


Figure D-17. — Trial 14, deposition on top of cylinder positioned 5 feet below release height.

Appendix E

Method used to qualitatively assess droplet coverage of cylindrical sampler, vertical surfaces, and disc placed on top of sampler is discussed in the letter dated June 17, 1980 from Chris Cunningham to John W. Barry.

Table E-1.-Mean coverage of vertical surface from 12 cylindrical samplers placed in each sample tree, aerial spray trials, Withlacoochee Seed Orchard Project, 1980.

Trial	Aircraft	Tree Species	Tree Number	Mean Surface/ Droplet Coverage (percent)	X
1	Stearman	Slash pine	1	64	
			2	63	
			3	66	
			4	66	
			5	65	
			6	62	
			7	64	
			8	58	63.5%
		Sand pine	9	81	
			10	79	
			11	73	
			11	73	
			12	71	76%
3	Stearman	Slash pine	1	76	
			2	92	
			3	74	
			4	76	
			5	62	
			5	62	
			6	75	
			7	70	
			8	68	74.1%
		Sand pine	*9*	*78*	
			10	*72*	
			11	*75*	
			12	*59*	*71%*
5	Stearman	Slash pine	1	27	
			2	26	
			3	28	
			4	25	
			5	38	
			6	30	
			7	35	
			8	32	30.1%

Trial	Aircraft	Tree Species	Tree Number	Mean Surface/ Droplet Coverage (percent)	$\bar{X}$
5	Stearman	Sand pine	9	35	
			10	39	
			11	31	
			12	37	35.5%
6	Stearman	Slash pine	1	67	
			2	77	
			3	75	
			4	79	
			5	63	
			6	47	
			7	58	
			8	62	66%
		Sand pine	9	81	
			10	75	
			11	88	
			12	80	81%
8	Stearman	Slash pine	1	62	
			2	69	
			3	58	
			4	62	62.8%
10	Hughes 500C	Slash pine	1	38	
			2	29	
			3	33	
			4	33	
			4	35	33.8%
		Sand pine	9	43	
			10	43	
			11	37	
			12	46	42.3%
11	Hughes 500C	Slash pine	1	98	
			2	100	
			3	94	
			4	98	97.5%
		Sand pine	9	98	
			10	95	
			11	93	
			12	98	96%

Trial	Aircraft	Tree Species	Tree Number	Mean Surface/ Droplet Coverage (percent)	$\bar{X}$
12	Hughes 500C	Slash pine	1	96	
			2	96	
			3	96	
			4	98	96.5%
		Sand pine	9	97	
			10	92	
			11	99	
			12	94	95.5%
13	Hughes 500C	Slash pine	1	99	
			2	88	
			3	93	
			4	92	93%
		Sand pine	9	96	
			10	93	
			11	95	
			12	88	93%
14	Hughes 500C	Slash pine	1	93	
			2	97	
			3	90	
			4	98	94.5%
		Sand pine	9	94	
			10	89	
			11	96	
			12	95	93.5%

Table E-2.-Mean coverage of 12 cylindrical samplers' vertical surfaces placed in each sample tree, ground sprayer trials, Withlacoochee Seed Orchard Project, 1980.

Trial	Sprayer	Tree Species	Tree Number	Surface Coverage (percent)	$\bar{X}$
4	FMC	Slash pine	13	94	
			14	98	
			15	96	
			16	88	94%
9	FMC	Slash pine	13	98	
			14	98	
			15	98	
			16	93	96.8%
15	FMC	Slash pine	13	96	
			14	100	
			15	93	
			16	88	94.3%
16	Withla - coochee Sprayer	Slash pine	13	92	
			14	84	
			15	97	
			16	78	87.8%

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

WO-FIDM Methods Application Group
2810 Chiles Road, Davis, CA 95616

REPLY TO: 5750 Aerial Application

June 17, 1980

SUBJECT: Withlacoochee Seed Orchard Project-Qualitative Kromekote Card Counting Exercise for Canopy and Tree Samplers

TO: John W. Barry, MAG

Following is a description of procedures to estimate droplet concentration on cylindrical samplers (Fresca cans). There were two Kromekote card collection surfaces, one on top of the can, circular in shape and recessed within the rim, and the other completely wrapped around the can vertical surface. The former was 2½ inches in diameter and the latter 4¼ inches X 8 3/16 inches.

Materials: Microscope and support equipment. Square centimeter (cm) grid (clear plastic). Data sheets.

Before beginning, a categorization scheme was set up to fit the data forms so that relative droplet stain density could be seen schematically as well as numerically. The droplet density categories were (in numbers of dots): 0, 1-10, 11-15, 25-50, and 50-.

Droplet density (per cm^2) were determined by eye (which had been trained through the use of a microscope to recognize the various categorized concentrations). For the discs from the can tops, however, a more accurate count was desired.

Two methods were employed in obtaining counts on the discs. Each method was used, where appropriate, according to the following criteria:

- If there were obviously less than 20 droplets/cm^2 then about six (6) squares were counted and an average among them was taken as the count.

- If there were twenty (20) or more droplets/cm^2, an "eyeball average" was used to find a single square to count which was to be the count for that card.

  Note: All of the above counts were made through a microscope at 7 to 30X magnification.

Project Notes: Some counts were extremely difficult to make because of:

- Rain damage which, besides smearing the droplets into each other, diluted the dye so that many dots were very faint.

- Wind effects, spreading of the droplets into each other making "mega-dots", for which accurate counts were often impossible. (After all, how many droplets made "that" blob?)

- Substantial counting error is probable for discs with high droplet concentrations as it was difficult for ones eyes to stay locked on the sample.

CHRIS CUNNINGHAM
Physical Science Aid

Appendix F

Description of helicopter wake phenomenon.

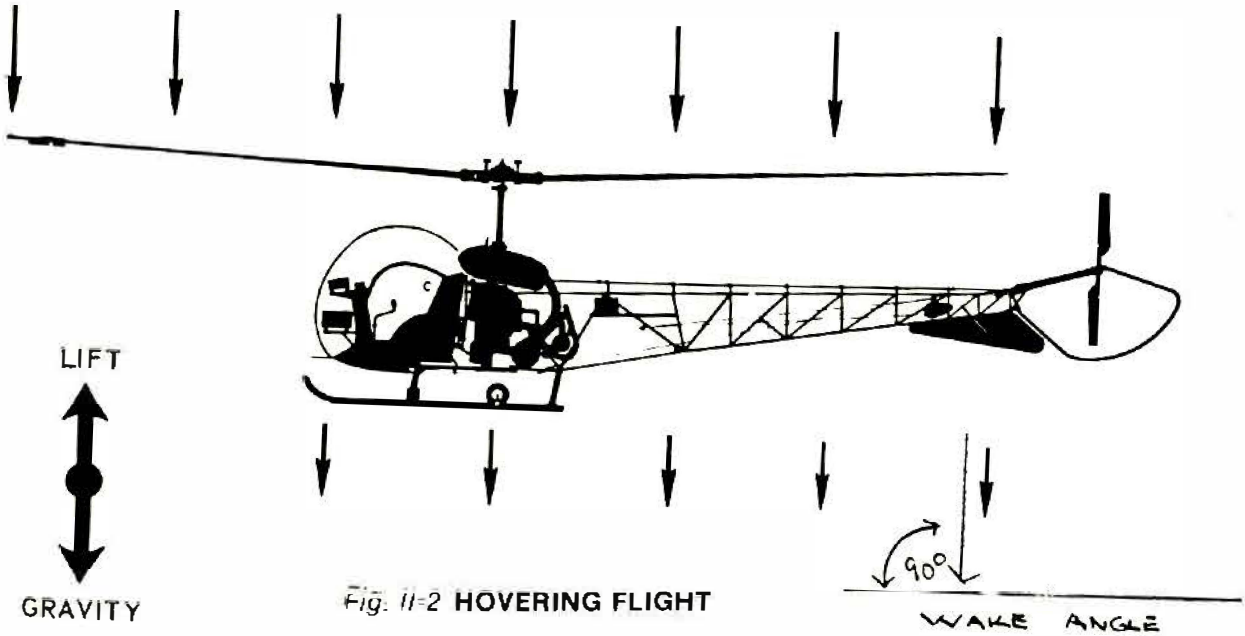


Fig. II-2 **HOVERING FLIGHT**

Figure F-1.–Forward flight helicopter wake.
Data From: Bell Helicopter Co. Helicopter techniques for aerial application, 1966.

FIG. II. 4

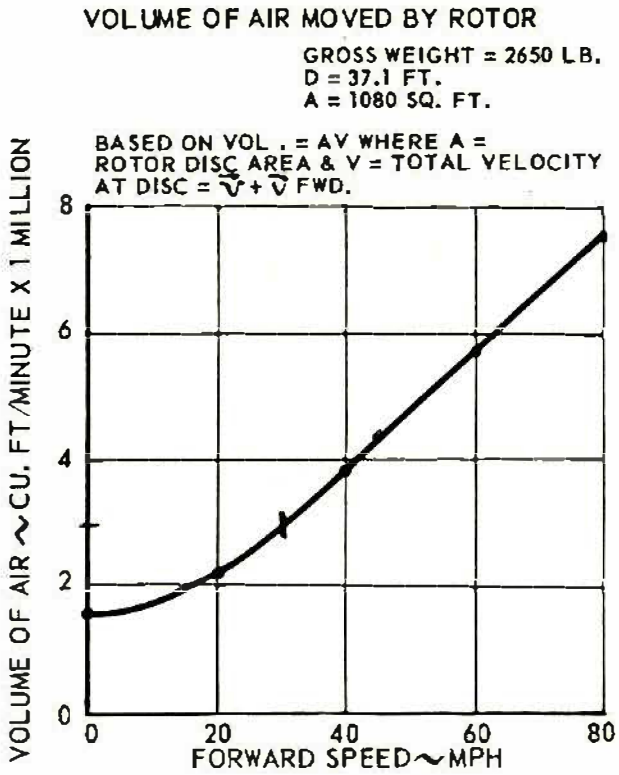


FIG. II. 5

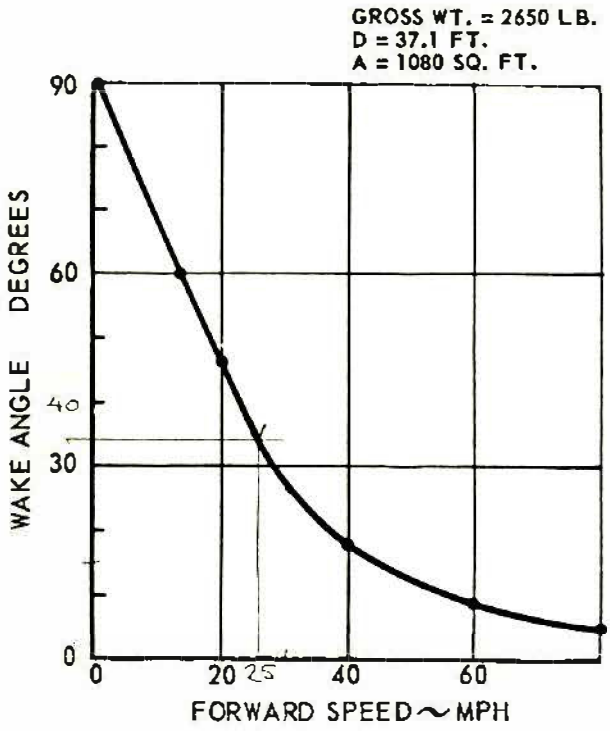
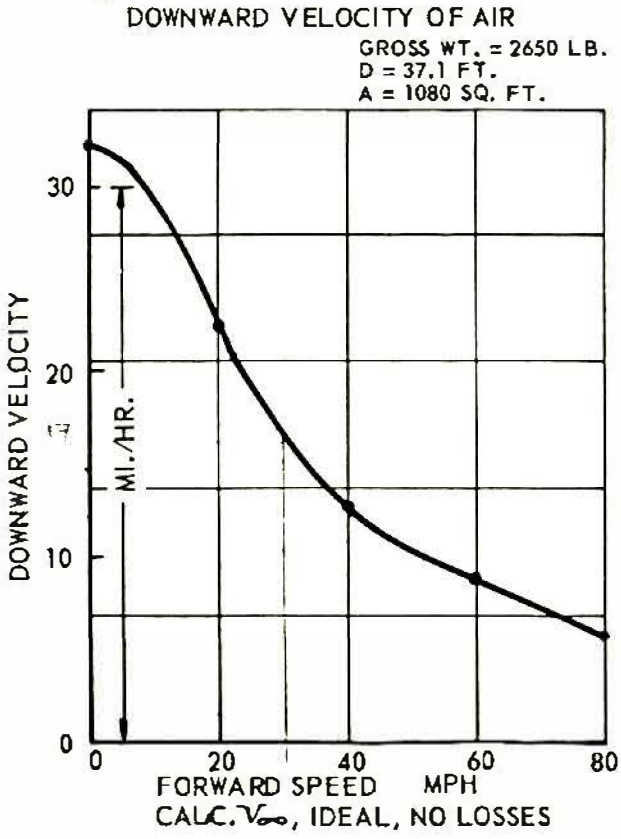


FIG. II. 6



DATA BASIS

These data are based upon a Bell helicopter with a 37.1 feet diameter main rotor while operating at a gross weight of 2,650 pounds.

Data From: Bell Helicopter Co. Helicopter techniques for aerial application, 1966.

Figure F-2.–Helicopter wake angles and downwash velocities.

Appendix G

Table G-1.-Collection efficiencies of 2-1/2" diameter can for various droplet sizes.

Drop Size (μm)	Wind Speed (mph) 2	4	10
50	2%	3%	10%
100	15%	21%	44%
200	51%	57%	78%
300	69%	74%	83%
350	74%	78%	84%
400	76%	81%	87%
500	83%	84%	90%

Note: Calculated by Bob Ekblad using Langmir and Blodgett calculations.

GPO 689-907

WITHLACOOCHEE